GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

no action adds OAH

Date: August 17, 1977

Project Title: "Low Flow Characterization and Expert Hydrologic Advice and Consultation."

Project No: E-20-617

Project Director: Dr. J. R. Wallace

Sponsor: Department of Natural Resources, Environmental Protection Division.

Agreement Period: From 7/1/77 Until 6/30/78

Type Agreement: Contract dated 6/30/77

Amount: $15,000

Reports Required: Quarterly Progress Reports

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Defense Priority Rating: N/A

Assigned to: Civil Engineering (School/Laboratory)

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Other

CA–3 (3/76)

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SPONSORED PROJECT TERMINATION

Date: 9/28/78

Project Title: Low Flow Characterization and Expert Hydrologic Advice and Consultation

Project No: E-20-617

Project Director: Dr. J. R. Wallace

Sponsor: Georgia Dept. of Natural Resources

Effective Termination Date: 6/30/78

Clearance of Accounting Charges: 6/30/78

Grant/Contract Closeout Actions Remaining: NONE

- _ Final Invoice and Closing Documents
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______

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CA–4 (3/76)

E-20-617

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INVESTIGATION INTO LOW FLOW OF SMALL GEORGIA STREAMS

by

Kurt J. Wiederkehr and James R. Wallace

Partial Completion Report
Project No. E-20-617
Environmental Protection Division
Department of Natural Resources
State of Georgia

February 1978

School of Civil Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

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CHAPTER I

INTRODUCTION

Background and Literature Review

Low Flow in Georgia

Estimates of low flows in streams are needed for a wide variety of reasons. In Georgia the most important reason is probably for use in the determination of the waste assimilation capacity, the amount of oxygen-consuming waste that can be released into a stream without turning it anaerobic. Low flow data is also needed for the development of domestic and industrial water supplies, and for cooling and irrigation.

The major cities in Georgia lie on large streams. All of these streams have gages with sufficient record length to permit the determination of low flows with good accuracy. With the development of new regions, there is a need for the use of many of the smaller streams. As it is economically unfeasible to gage all possible sites, and base flow measurements even under favorable conditions have to be made over several years to obtain accurate low flow estimates, methods for at least a rough estimate of low flows which do not require flow measurements are needed.

The first research on low flow in small Georgia streams was induced by the drought of 1954, during which base flow measurements were made at about a thousand sites all over the State [1]. By correlation with continuous record stations, minimum average flows for various time intervals were computed [2]. Because for most sites only 1 or 2 base flow measurements were available, the results of these correlations are subject to considerable error.

Nevertheless, the high number of sites gaged allowed a determination of regions with similar low flow yields (flow per unit area) during the 1954 drought. However, the drought varied in severity over the State; in some areas it was the most severe of record, in other regions it was only the sixth most severe. At 55 continuous record stations values for the average 7-day 10 and 20-year flows were computed. These flows were then grouped in the regions defined by low flow yields during the 1954 drought, and values for minimal, maximal and average flow within each of those regions were estimated [3]. The utility of such information is limited because boundaries for the statistical 10 and 20-year low flows are certainly different from those for a single drought event.

In a study on the headwaters of the Yellow River, an area with a high density of continuous and partial record stations, Carter and Gannon [4] estimated low flow values for various time intervals and return periods along all perennial streams. Correlations with continuous stations were made on the basis of a single base flow measurement, therefore, accuracy of the low flow values at those partial record sites is not very high. Some regional pattern can be recognized in their low flow data, but no relation to geology or physiography was reported.

In 1971 values for minimal flow in Georgia streams for each year of record and for a wide range of consecutive days were published for all continuous record stations [5].

In the process of reviewing the gaging network in Georgia, Carter [6] made a regression analysis between streamflow characteristics and various physical and climatic factors like slopes, watershed size, stream length, and precipitation. Contrary to high and average flows, low flows correlated badly with those factors.

Day [7] used a deterministic approach to simulate monthly flows on six small Georgia watersheds. After calibrating a modified Haan model (6 parameters) over a three-year period in each watershed, the model was used to simulate a longer period based on the availability of precipitation data. Analysis of the simulated streamflow showed that in three of the watersheds low flows were satisfactorily predicted.

Partial base flow measurements have been made in Georgia since 1937, but in a rather unsystematic way. In 1957, a network of 127 low flow partial record stations was established. Low flow values are currently being determined for these and for all continuous record stations with records of sufficient length (see Chapter II).

Studies of Low Flows in Other Areas

Most of the literature in the field of estimating low flows deals with statistical analysis of continuous records or with correlation procedures for sites with only partial base flow measurements. Much work has also been done on base flow recession [8], but it is mostly an analysis of a given hydrograph or recession under idealized conditions. No way has yet been found to determine recession constants and other parameters from basin characteristics. Riggs [9] points out that not only transmissivity and storage capacity of ground water bodies are important, but also their connection to the stream, and all this cannot be identified from field or geologic map examinations.

Several authors have tried to correlate low flows with drainage basin characteristics; one of them has been mentioned earlier [6]. The most comprehensive investigation was made by Thomas and Benson [10] in 4 different regions of the U. S. The estimation of the low flows was poor; standard errors of estimate were in the magnitude of several hundred percent. Osborne

[11] claims to have successfully related low flow to basin characteristics.

If a good network of streamflow is available, interpolation of data certainly is a legitimate approach. Singh and Stall [12] determined the 7-day 10-year low flow every 3 to 4 miles along streams in Illinois. They used data from gaging stations, regional low flow vs. drainage area curves, effluent vs. population relations and took into account soil, groundwater hydrology and man-made structures.

Schneider [13] related low flows in a Pennsylvania watershed during a period in the fall of 1962 to the underlying geologic formations. He observed average low flow yields of 0.01 to 0.1 cfs/sq mi in shale, 0.1 to 0.2 cfs/sq mi in sandstones, conglomerates and shales, and 0.3 to 0.4 cfs/sq mi in coarse sandstones. The greatest variability, from 0.0 to 1.0 cfs/sq mi, was observed in dolomite and limestone.

In the Dresden area (East Germany) maps for 15-day low flow yields (flow per unit area) with a 2 and 20-year recurrence interval were derived [14] based on about 50 continuous record stations with watersheds mostly below 200 sq mi. Geology, precipitation and river length were taken into account in outlining about 50 different areas with similar low flow yields. Values for other return periods can be calculated by using linear relationships with regionalized parameters.

Riggs [15] observed that in a frequency plot of the low flows in the Tallapoosa River based on 32 years of record, the three lowest values did not fit within a statistical distribution defined by the other data. At four surrounding raingages, all of them outside the watershed, 68 years of precipitation records were available. During the common period of record, a correlation was made between the annual minimal 7-day low flow and the average precipitation at the four raingages during two periods of the year

(January to July and August to September). With the regression coefficients obtained, the runoff could be simulated for the 68 years by utilizing available precipitation records. It turned out that the three values mentioned above were the lowest of the entire 68-year period, and, when analyzed within this longer period the three values were consistant with the distribution of the data.

Geology and Precipitation

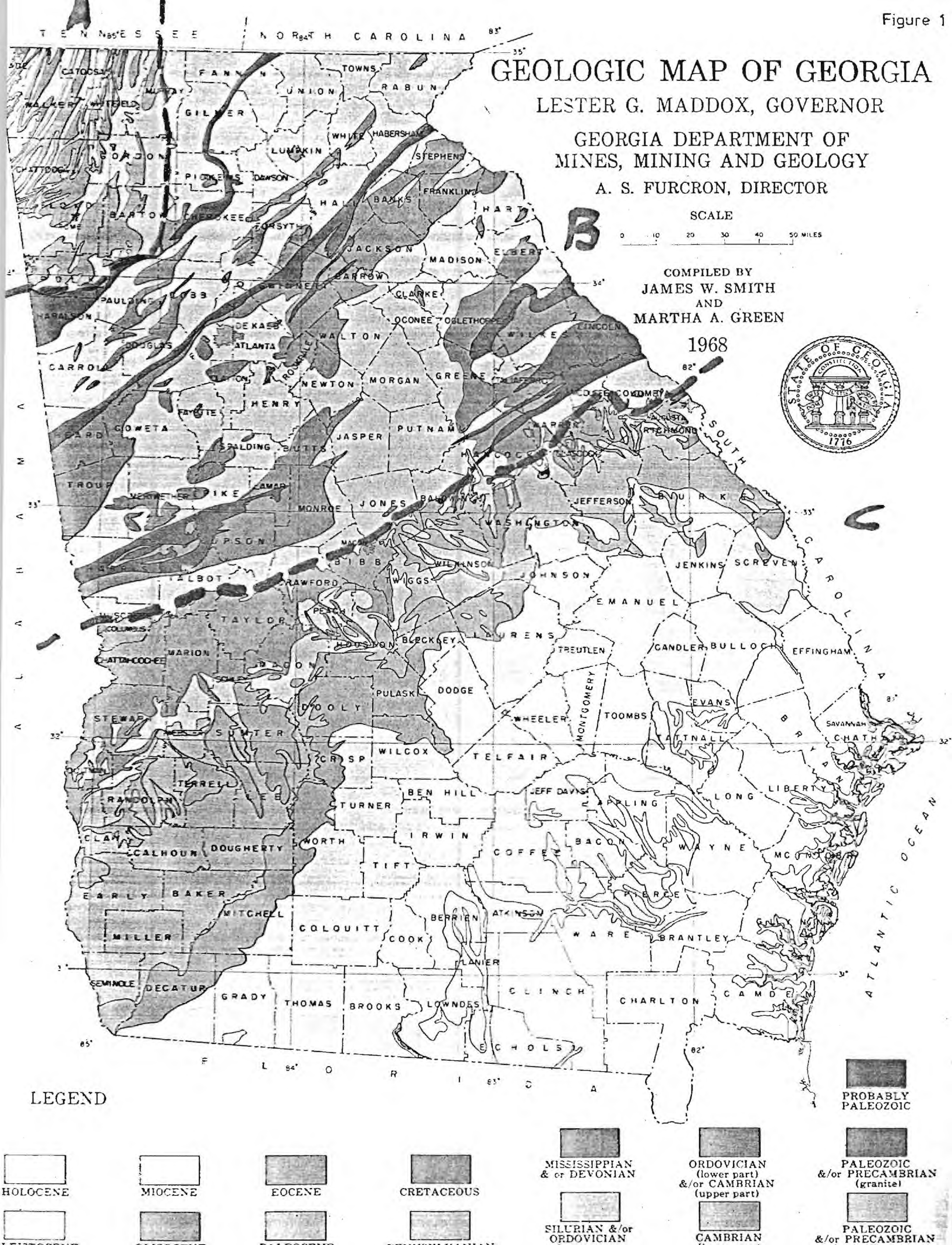
Georgia is divided into 3 geologic regions (Figure 1), the Valley and Ridge (A), the Piedmont and Blue Ridge (B), and the Costal Plain (C).

The Valley and Ridge province in northwest Georgia is underlain by folded consolidated sedimentary rocks like shale, slate, dolomite, limestone, quartzite, and sandstone. Original structures have been strongly eroded, and the limestones and dolomites contain solution cavaties.

The Blue Ridge, with elevations up to 5000 ft, and the hills of the Piedmont, even though physiographically they are quite different, both consist of methamorphic igneous rocks like gneiss and schist with younger intrusions, mostly granite. As a result of repeated deformations, the structures are extremely complex, including many faults and shear zones. These rocks are weathered to a thickness of a few to 80 ft, depending on the type of rock and the physiography.

The Costal Plain province, which lies south of the so-called Fall Line, is underlain by stratified sediments like clay, silt, sand, limestone, and dolomite. The oldest of these strata surface close to the Fall Line, and the younger formations cover the older ones to progressively thicker depths as one procedes to the south and east. The surface also dips in a southeastern direction, with slopes diminishing from about 30 to close to zero feet per mile.

Figure 1


GEOLOGIC MAP OF GEORGIA
LESTER G. MADDOX, GOVERNOR
GEORGIA DEPARTMENT OF MINES, MINING AND GEOLOGY
A. S. FURCRON, DIRECTOR
SCALE
0 10 20 30 40 50 MILES
COMPILED BY
JAMES W. SMITH
AND
MARTHA A. GREEN
1968
STATE OF GEORGIA
1776
B
C
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
ALABAMA
FLORIDA
ATLANTIC OCEAN
FANNIN
TOWNS
UNION
RABUN
GILMER
WHITE
HABERSHAM
LUMPKIN
STEPHENS
PICKENS
DAWSON
HALL
BANKS
FRANKLIN
HART
FORSYTH
JACKSON
MADISON
ELBERT
BARROW
CLARKE
OCONEE
OGLETHORPE
WILKES
LINCOLN
WALTON
NEWTON
MORGAN
GREENE
HENRY
JASPER
PUTNAM
HANCOCK
SPALDING
BUTTS
PIKE
LAMAR
MONROE
JONES
UPSON
TALBOT
CRAWFORD
BIBB
TWIGGS
WILKINSON
WASHINGTON
JEFFERSON
BURKE
JENKINS
SCREVEN
JOHNSON
EMANUEL
TAYLOR
PEACH
HOUSTON
BLECKLEY
LAURENS
TREUTLEN
CANDLER
BULLOCH
EFFINGHAM
MARION
CHATTAHOOCHEE
MACON
PULASKI
DODGE
MONTGOMERY
TOOMBS
EVANS
STEWART
DOOLY
WHEELER
TATTNALL
SUMTER
CRISP
WILCOX
TELFAIR
SAVANNAH
CHATHAM
BRYAN
TERRELL
LEE
TURNER
BEN HILL
JEFF DAVIS
APPLING
LONG
LIBERTY
RANDOLPH
CLAY
CALHOUN
DOUGHERTY
WORTH
IRWIN
COFFEE
BACON
WAYNE
MCINTOSH
TIFT
EARLY
BAKER
MITCHELL
BERRIEN
ATKINSON
PIERCE
WARE
BRANTLEY
MILLER
COLQUITT
COOK
LANIER
SEMINOLE
DECATUR
GRADY
THOMAS
BROOKS
LOWNDES
CLINCH
CHARLTON
CAMDEN
ECHOLS
CATOOSA
MURRAY
WALKER
WHITFIELD
GORDON
CHATTOOGA
FLOYD
BARTOW
CHEROKEE
POLK
PAULDING
COBB
GWINNETT
HARALSON
DEKALB
ATLANTA
DOUGLAS
ROCKDALE
CARROLL
CLAYTON
FAYETTE
COWETA
HEARD
TROUP
MERIWETHER
HARRIS
MUSCOGEE
COLUMBUS
COLUMBIA
MCDUFFIE
TALIAFERRO
WARREN
GLASCOCK
AUGUSTA
RICHMOND
BALDWIN
MACON
LEGEND
PROBABLY PALEOZOIC
HOLOCENE
MIOCENE
EOCENE
CRETACEOUS
MISSISSIPPIAN & or DEVONIAN
ORDOVICIAN (lower part) &/or CAMBRIAN (upper part)
PALEOZOIC &/or PRECAMBRIAN (granite)
SILURIAN &/or ORDOVICIAN
CAMBRIAN
PALEOZOIC &/or PRECAMBRIAN

EXPLANATIONS TO GEOLOGIC MAP

Precambrian	Schist and gneiss
Early and middle Cambrian	Sandstone, quartzite, siltstone, shale, phyllite, dolostone, limestone
Late Cambrian and early Ordovician	Dolostone and limestone
Middle and late Ordovician, Silurian	Siltstone shale, sandstone, limestone, thin iron ore beds
Devonian	Little black shale and chert, sandstone and siltstone
Mississippian	Limestone and shale
Pennsylvanian	Sandstone, shale, siltstone and coal
Cretaceous	Sand, clay and gravel
Paleocene	Limestone, clay, sand, iron ore and bauxite
Eocene	Limestone, sandstone, clay, marl, Fuller's earth, chert
Oligocene	Limestone and sand
Miocene	Limestone, sand, clay, some dolomite
Pleistocene, Holocene	Sand and some clay and silt

Precipitation is distributed fairly evenly over the whole state with an annual average depth of about 50 inches. The Blue Ridge is an exception; here the annual average reaches up to 80 inches due to orographic effects. Monthly precipitation is lowest in late summer (about 2.5 inches) and highest is winter. Most of the summer precipitation occurs during thunderstorms.

Throughout Georgia annual lowflows occur during September or October.

Objectives and Procedures

The literature review shows that there is no generally accepted method for the determination of low flows in ungaged streams. As long as this is the case, interpolation of data from gaging stations, with merely qualitative considerations of terrestrial and metereological factors, remains the only possibility to solve practical problems. The objective of the following chapter (Chapter 2) is a state-wide estimation of low flow yields based on newly-available data at more than 150 continuous and partial record gaging stations. Zones with similar 7 day average lowflow were outlined for different return periods. By comparison with geologic and topographic maps and Landsat imagery, relations to geology, topography and vegetation density could be determined.

In Chapter 3, a different approach is taken. All over Georgia a fairly dense network of raingages with long records is available. If a relationship (a model) between precipitation and low flow could be found, and the parameters in this model could be regionalized or related to physical characteristics, low flows in ungaged streams could be determined. The concept of correlation between annual low flows and antecedent precipitation was used on 6 small watersheds in west Georgia. Precipitation periods ranging from a few months to 3 years were tested to obtain an optimal correlation.

CHAPTER II

REGIONALIZED 7-DAY LOW FLOW YIELDS FOR GEORGIA

Data Source

The Georgia Department of Natural Resources currently is preparing a report which will present low flow data for 147 continuous record stream gaging stations and 102 low flow partial record stations [16]. For the continuous record stations, the basic method of analysis was the use of graphical fitting on extreme-log (Weibull) paper. Average low flows for 1, 7, 14, 30, 60, 90, 120, and 183 days with a recurrence interval of 2, 5, and 10 years were estimated. For stations with a longer record, low flows with recurrence intervals of 20, 30, and 50 years were calculated. For stations with short record periods, results were adjusted by correlation with adjacent long-term stations to eliminate effects of short-term climatic trends.

Base flows measured at partial record stations were correlated with concurrent flows at surrounding continuous record stations. The continuous record station providing the best correlation to the partial record station was then chosen for use in extending the partial record. Determination of low flows for 1, 7, 30, 60, and 90 days with a recurrence interval of 2, 5, 10, 20, and 30 years was then based on the extended record. For some stations in the lower costal plain, the only value given was 0.0 cfs for the 7-day 10-years low flow.

Watershed Size and Low Flow

If the low flow yield (in cfs/mi^2 or l/s km^2) were independent of the watershed size, it could be determined by simply dividing the flow at the gage by the watershed area to get a yield valid over the whole watershed. For large watersheds there are several reasons for a lack of independence: Deep entrenchment increases the yield along the channel; a large river flows through different geologic and physiographic provinces with wide variations of low flow yield; man-made structures influence the flow in most large rivers; etc. For these reasons, only watersheds with a size of less than 500 mi^2 were used in this study. Restricting the size of the watersheds analyzed reduced the number of stations for the 10-year recurrence interval to 80 continuous and 98 partial record stations (Figure 2). The number of stations for which low flows with other recurrence intervals were determined, the distribution of stations over the 3 geologic provinces and the distributions of partial and continuous record stations are shown in Tables 1 and 2.

If the 7-day low flow yield with an N-year recurrence interval (Q7LN) were independent of the watershed size (A), one would fail to reject the hypothesis b = 0, where b is defined by the regression equation

$$Q7LN = a + b \cdot A$$

Using an F-statistic, we can accept the hypothesis if $F_0 < F_{\alpha,\ 1,\ n-2}$ with α as level of acceptance (i.e., percentage of cases we would reject even if b = 0) and n as number of watersheds used in the computation of the value of b.

F_0 was computed with the values of the 2, 5, 10, and 20-year return periods for the whole state and each of the 3 geologic provinces separately using the formula

$$F_0 = \frac{\hat{\beta}\ S_{xy}(n-2)}{S_{yy} - \hat{\beta}\ S_{xy}}$$

where $$\hat{\beta} = \frac{S_{xy}}{S_{xx}}$$

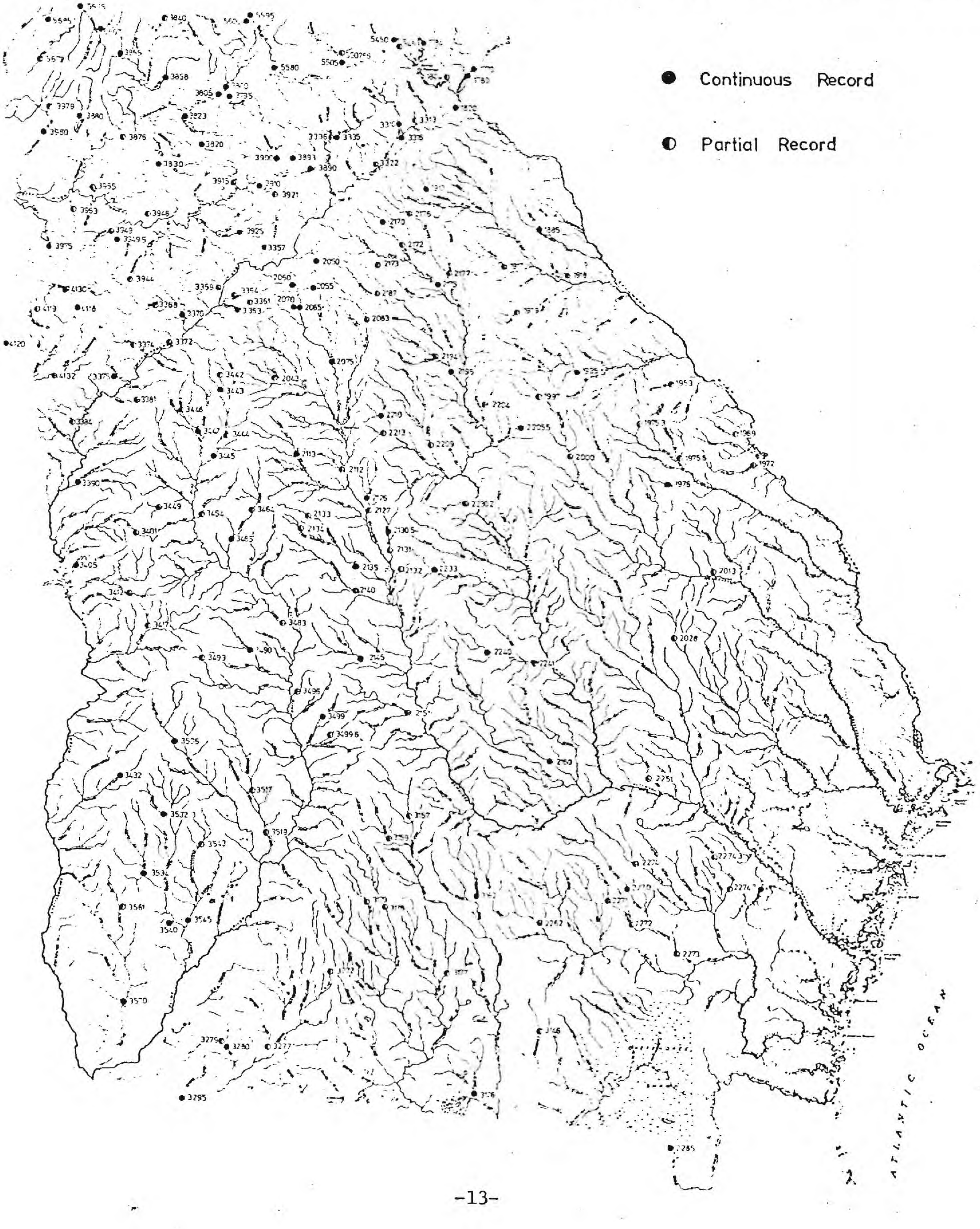
Table 1. Size Distribution of Watersheds up to 500 mi^2

Recurrence Interval	Province	Size (mi^2) 0-50	50-100	100-150	150-200	200-300	300-400	400-500	Total No. in Province
2 and 5 years	Blue Ridge and Piedmont	47	24	10	6	11	4	3	105
	Ridge and Valley	8	5	2	2	0	0	1	18
	Costal Plain	12	7	5	5	2	3	3	37
	Total in size range	67	36	17	13	13	7	7	160
10 years	Blue Ridge and Piedmont	47	24	10	6	11	4	3	105
	Ridge and Valley	8	5	2	2	0	0	1	18
	Costal Plain	16	13	12	5	3	3	3	55
	Total in size range	71	42	24	13	14	7	7	178
20 years	Blue Ridge and Piedmont	47	22	8	6	11	4	3	101
	Ridge and Valley	8	5	2	2	0	0	1	18
	Costal Plain	11	7	5	5	2	1	3	34
	Total in size range	66	34	15	13	13	5	7	153

Table 2. Partial and continuous record stations

Recurence Interval	2 and 5 years		10 year		20 year	
Province	cont	part	cont	part	cont	part
Blue Ridge and Piedmont	54	51	54	51	50	51
Ridge and Valley	9	9	9	9	9	9
Coastal Plain	17	20	17	38	14	20
	80	80	80	98	73	80

Gages with Watersheds < 500mi^2



$$S_{xx} = \sum(x_i - \overline{x})^2$$

$$S_{yy} = \sum(y_i - \overline{y})^2$$

$$S_{xy} = \sum y_i(x_i - \overline{x})$$

Results are shown in Table 3.

We fail to reject the hypothesis $b = 0$ for all provinces at the 10% level and for the whole State even at 50% level and can, therefore, conclude that the low flow yield is independent of the watershed size.

For all recurrence intervals up to 20 years for which data was available, the low flow yield for each watershed was computed. The ratio Q7L2/Q7L10 was also determined (Tables 4 and 5).

Regionalization

The values of the 7-day average low flow per unit area for 2, 5, 10, and 20-year return periods and the values of the ratio Q7L2/Q7L10 were plotted on transparent sheets. To detect relations between low flow characteristics and geology, topography and vegetation density, these plots could be laid over geologic and topographic maps and Landsat imagery.

For each return period, zones which showed similar low flow magnitude and variance were outlined. Mean and standard deviation of the low flow of the watersheds within these zones were computed. Wherever it seems justified, the boundaries of the zones followed geologic or topographic boundaries. Otherwise, the position of the boundary was determined by interpolation between two watersheds lying in different zones. If one watershed obviously extended over zones with different yields, its value was included in the zone in which its largest part lies. The same procedures were used for the Q7L2/Q7L10 ratio.

Table 3. F-Statistic for 7-Day Low Flows

Recurrence Interval	2 yr.			5 yr.			10 yr.			20 yr.		
Province	n	F_o	F_*	n	F_o	F_*	n	F_o	F_*	n	F_o	F_*
Blue Ridge and Piedmont	105	1.27	2.76	105	0.65	2.76	105	0.50	2.76	101	0.38	2.76
Ridge and Valley	18	0.35	2.01	18	0.78	3.01	18	0.77	3.01	18	0.74	3.01
Coastal Plain	37	2.64	2.85	37	2.85	2.85	55	1.54	2.82	34	2.01	2.86
All Georgia	160	0.00	2.74	160	0.09	2.74	178	0.06	2.74	153	0.04	2.74

$* \; F = F_{0.1,\, 1,\, n-2}$

TABLE 4 Continous Record Stations

STATION	AREA (SQMI)	Q7L2 (CFS/SQMI)	Q7_5 (CFS/ SQMI)	Q7L10 (CFS/SQMI)	Q7L20 (CFS/SQMI)	QML2/Q7_10
1770.0	207.0	1.014	.725	.580	.507	1.75
1780.0	256.0	1.270	.762	.449	.250	2.83
1784.0	56.5	1.027	.850	.743		1.38
1820.0	32.5	.769	.523	.431	.369	1.79
1845.0	35.8	.391	.212	.151	.109	2.59
1912.0	61.1	.622	.507	.458	.426	1.36
1935.0	291.0	.048	.033	.018	.008	2.69
1976.0	28.0	.307	.246	.214	.182	1.43
2050.0	1.6	.113	.050	0.000	0.000	
2055.0	2.2	.233	.170	.112	.090	2.08
2060.0	1.0	.184	.112	.061	0.000	3.00
2065.0	134.0	.179	.090	.037	.023	4.80
2070.0	5.5	.253	.208	.181	.159	1.40
2075.0	378.0	.196	.082	.055	.042	3.52
2113.0	105.0	.229	.152	.089	.067	2.58
2126.0	72.2	.037	.009	.003		10.80
2130.5	29.0	.072	.034	.024	.020	2.96
2135.0	182.0	.143	.088	.047	.030	3.06
2145.0	108.0	.324	.222	.194	.176	1.67
2160.0	329.0	.013	.009	.008		1.69
2170.0	17.3	.428	.289	.191	.139	2.24
2175.0	398.0	.327	.196	.113	.075	2.89
2195.0	436.0	.252	.163	.119	.080	2.12
2205.5	15.0	.127	.067	.059	.051	2.16
2210.0	24.0	.175	.117	.088	.067	2.00
2233.0	31.0	.206	.158	.116	.090	1.78
2240.0	62.9	.041	.017	.010	.006	4.19

Table 4 Continuous Record Stations (Cont'd.)

STATION	AREA (SQMI)	Q7L2 (CFS/SQMI)	Q7L5 (CFS/ SQMI)	Q7L10 (CFS/SQMI)	Q7L20 (CFS/SQMI)	QML2/Q7L10
2261.0	210.0	0.000	0.000	0.000	0.000	
2270.0	150.0	0.000	0.000	0.000	0.000	
2285.0	160.0	.003	0.000	0.000	0.000	
3280.0	60.0	.075	.025	.013	.006	5.92
3295.0	237.0	.160	.063	.042	.039	3.80
3310.0	150.0	.933	.700	.600	.547	1.56
3316.0	315.0	.889	.730	.651	.603	1.37
3335.0	153.0	.752	.542	.451	.386	1.67
3357.0	72.0	.250	.153	.082	.058	3.05
3363.0	86.8	.219	.161	.127	.104	1.73
3370.0	246.0	.179	.098	.061	.036	2.93
3375.0	37.0	.432	.324	.249	.195	1.74
3390.0	182.0	.192	.093	.066	.049	2.92
3405.0	61.7	.259	.149	.110	.086	2.35
3432.0	70.0	.429	.271	.214	.200	2.00
3443.0	17.2	.314	.215	.128	.099	2.45
3445.0	272.0	.180	.099	.055	.030	3.27
3447.0	101.0	.129	.069	.045		2.89
3465.0	186.0	.145	.086	.059	.030	2.45
3490.0	93.4	1.328	1.188	1.135	1.113	1.17
3499.0	45.0	.113	.067	.053	.047	2.13
3506.0	197.0	.249	.157	.127	.107	1.96
3534.0	188.0	.420	.266	.223	.202	1.88
3540.0	14.0	0.000	0.000	0.000		
3545.0	320.0	.050	.021	.014		3.56
3570.0	485.0	.120	.060	.037	.025	3.22
3795.0	135.0	.778	.691	.607	.541	1.28

Table 4 Continuous Record Stations (Cont'd.)

STATION	AREA (SQMI)	Q7L2 (CFS/SQMI)	Q7L5 (CFS/ SQMI)	Q7L10 (CFS/SQMI)	Q7L20 (CFS/SQMI)	QML2/Q7L10
3800.0	90.0	.567	.489	.444	.400	1.28
3805.0	238.0	.672	.546	.504	.462	1.33
3820.0	21.1	.142	.066	.046	.034	3.09
3823.0	142.0	.352	.261	.211		1.67
3830.0	5.6	.143	.089	.071	.061	2.00
3855.0	38.4	.443	.391	.365	.352	1.21
3858.0	64.9	.083	.063	.052	.043	1.59
3880.0	34.5	.200	.177	.157	.145	1.28
3890.0	103.0	.951	.699	.602	.534	1.58
3893.0	20.5	.854	.659	.561	.512	1.52
3900.0	84.7	.968	.756	.661	.602	1.46
3910.0	466.0	.794	.601	.536	.472	1.48
3925.0	60.5	.231	.122	.078	.048	2.98
3949.5	26.0	.085	.042	.023	.012	3.67
3975.0	109.0	.349	.312	.294	.257	1.19
3980.0	193.0	.389	.352	.321	.306	1.21
4118.0	18.0	.206	.128	.089	.056	2.31
4120.0	444.0	.214	.128	.085	.059	2.50
4130.0	89.0	.169	.093	.057	.034	2.94
5450.0	45.5	.835	.681	.593	.549	1.41
5505.0	74.8	.642	.561	.468	.428	1.37
5580.0	177.0	.910	.746	.655	.627	1.39
5595.0	352.0	.767	.432	.330	.253	2.33
5600.0	70.9	.790	.663	.606	.550	1.30
5675.0	428.0	.257	.234	.201	.190	1.29
5685.0	50.6	.095	.079	.055	.049	1.71

Table 5 Low Flow Partial Record Stations

STATION	AREA (SQMI)	Q7L2 (CFS/SQMI)	Q7L5 (CFS/ SQMI)	Q7L10 (CFS/SQMI)	Q7L20 (CFS/SQMI)	QML2/Q7L10
1804.0	26.0	.885	.615	.462	.423	1.92
1917.0	89.0	.348	.225	.124	.083	2.82
1918.0	44.0	.145	.068	.043	.027	3.37
1919.0	31.0	.284	.161	.116	.084	2.44
1953.0	33.3	.063	.045	.025	.011	2.53
1969.0	29.4	.442	.374	.320	.272	1.38
1972.0	71.0	.543	.486	.443	.414	1.23
1975.3	7.5	.063	.039	.028	.019	2.24
1975.6	33.2	.482	.392	.361	.301	1.33
1997.0	33.0	.091	.052	.036	.022	2.50
2000.0	242.0	.058	.033	.020	.010	2.92
2013.0	23.0	.083	.052	.037	.026	2.21
2028.0	55.0			0.000		
2043.0	50.0	.300	.186	.102	.072	2.94
2053.0	99.0	.303	.182	.090	.060	3.37
2112.0	57.0	.228	.137	.077	.053	2.95
2127.0	108.0	.023	.010	.004	.002	5.95
2131.0	79.0	.033	.011	0.000	0.000	
2132.0	11.0	.427	.355	.291	.255	1.47
2133.0	27.7	.238	.155	.097	.054	2.44
2134.0	16.8	.167	.107	.060	.039	2.80
2140.0	147.0	.075	.041	.020	.012	3.67
2151.0	155.0	.071	.041	.035	.031	2.00
2172.0	128.0	.297	.172	.094	.061	3.17
2173.0	9.9	.121	.057	.021	.012	5.71
2176.0	70.0	.529	.343	.229	.171	2.31
2177.0	61.0	.295	.138	.062	.034	4.74

Table 5 Low Flow Partial Record Stations (Cont'd.)

STATION	AREA (SQMI)	Q7L2 (CFS/SQMI)	Q7L5 (CFS/ SQMI)	Q7L10 (CFS/SQMI)	Q7L20 (CFS/SQMI)	QML2/Q7L10
2137.0	54.0	.333	.204	.159	.107	2.69
2194.0	61.0	.197	.138	.107	.084	1.85
2204.0	44.0	.055	.039	0.000	0.000	?
2209.0	262.0	.122	.073	.050	.029	2.46
2213.0	5.5	.145	.093	.076	.069	1.90
2230.2	60.0	.070	.038	.028	.018	2.47
2241.0	316.0	.060	.025	.014	.009	4.32
2251.0	69.0			0.000		
2262.0	235.0			0.000		
2271.0	61.0			0.000		
2272.0	111.0			0.000		
2273.0	438.0	.012	.007	.004	.001	3.12
2274.0	112.0			0.000		
2274.3	49.0			0.000		
2274.7	63.0			0.000		
3146.0	143.0			0.000		
3157.0	112.0			0.000		
3159.0	137.0			0.000		
3162.0	90.0			0.000		
3176.0	193.0	.031	.015	.011	.008	2.90
3177.0	132.0			0.000		
3178.0	145.0			0.000		
3179.0	47.0			0.000		
3272.0	96.0			0.000		
3277.0	104.0	.008	.003	.003	.001	3.15
3279.0	19.0	.153	.063	.038	.021	4.03
3313.0	3.1	1.065	.903	.839	.806	1.27

Table 5 Low Flow Partial Record Stations (Cont'd.)

STATION	AREA (SQMI)	Q7L2 (CFS/SQMI)	Q7L5 (CFS/ SQMI)	Q7L10 (CFS/SQMI)	Q7L20 (CFS/SQMI)	QML2/Q7L10
3322.0	9.0	.533	.344	.222	.156	2.40
3336.0	31.3	.863	.639	.575	.479	1.50
3359.0	15.0	.373	.293	.240	.193	1.56
3361.0	27.8	.180	.083	.031	.018	5.86
3364.0	38.2	.188	.126	.097	.079	1.95
3368.0	50.0	.112	.052	.030	.016	3.73
3372.0	29.0	.331	.190	.124	.079	2.67
3374.0	43.0	.326	.205	.135	.093	2.41
3381.0	18.0	.313	.213	.144	.106	2.17
3384.0	57.0	.368	.281	.228	.193	1.62
3401.0	22.2	.135	.072	.054	.038	2.50
3412.0	42.6	.028	.007	.003	.002	8.57
3417.0	17.1	.058	.018	.009	.005	6.67
3442.0	6.0	.483	.383	.283	.250	1.71
3444.0	194.0	.211	.124	.072	.042	2.93
3446.0	38.0	.113	.053	.039	.029	2.87
3449.0	4.5	.222	.144	.111	.089	2.00
3454.0	101.0	.139	.069	.035	.020	3.89
3464.0	96.0	.115	.056	.027	.013	4.23
3483.0	139.0	.345	.252	.223	.209	1.55
3493.0	44.0	.841	.705	.682	.636	1.23
3496.0	39.0	.641	.462	.410	.385	1.56
3499.6	24.0			0.000	-	
3517.0	265.0	.275	.174	.143	.121	1.92
3519.0	405.0	.395	.272	.220	.198	1.60
3532.0	52.0	.500	.365	.308	.286	1.63
3543.0	63.0	.190	.111	.092	.081	2.07

STATION	AREA (SQMI)	Q7L2 (CFS/SQMI)	Q7L5 (CFS/ SQMI)	Q7L10 (CFS/SQMI)	Q7L20 (CFS/SQMI)	QML2/Q7L10
3551.0	49.0			0.000		
3840.0	108.0	.296	.259	.231	.213	1.28
3876.0	66.0	.394	.364	.333	.318	1.18
3915.0	64.0	.453	.313	.234	.188	1.93
3921.0	22.0	.273	.159	.109	.073	2.53
3944.0	40.0	.168	.068	.035	.016	4.79
3946.0	37.8	.185	.130	.111	.098	1.67
3949.0	95.0	.600	.474	.400	.326	1.50
3955.0	14.8	.243	.182	.155	.142	1.57
3963.0	24.0	.458	.342	.304	.279	1.51
3979.0	36.0	.022	.018	.012	.009	1.79
4119.0	237.0	.211	.114	.072	.041	2.94
4132.0	210.0	.205	.119	.076	.046	2.69
5453.0	6.1	.576	.493	.444	.411	1.30
5507.6	11.1	.514	.360	.351	.342	1.46
5667.0	169.0	.243	.219	.189	.166	1.28
5672.0	73.0	.110	.099	.077	.071	1.43

Not only the placement of the boundaries but also the number of different zones to be outlined is subjective to a certain degree. This is especially true for areas with few gaging stations (like the eastern part of the Piedmont or the Lower Coastal Plain) or in areas with a high variance (like parts of the central Piedmont). Ten zones were outlined for the 2 and 5-year return periods and nine for 10 and 20-year return periods. For the Q7L2/Q7L10 ratio only 4 zones with clearly different magnitude and variances could be found.

The zones and average and standard deviation of the low flows are shown in Figures 3 to 7. The number of watersheds and the standard deviation as a percent of the average in each zone is shown in Tables 6 and 7.

Conclusions

The two boundaries which separate the State into 3 geologic regions are clearly reflected in low flow yields. These sections can therefore be discussed separately. Some of the zones within them can again be explained by geology, some by topography, but for many features no explanation can be found. The use of Landsat imagery to detect influences of the vegetation did not produce any improvement in low flow estimates.

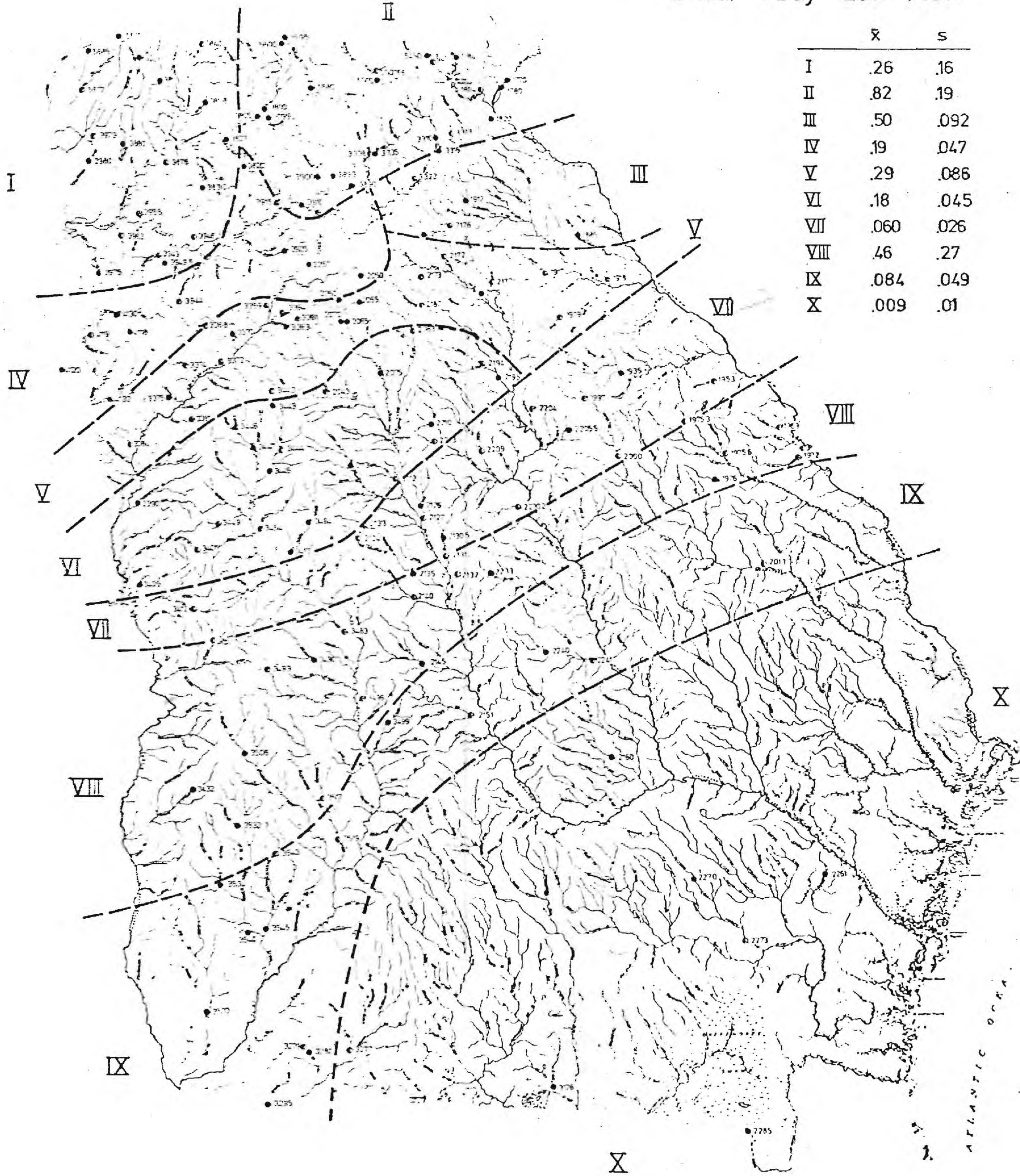
In the Valley and Ridge section some of the watersheds have quite high low flows (Q7L10 about 0.3 cfs/mi^2). There was no pattern found that would allow further grouping, and no relation to geology and topography could be seen. It is possible, though, that a closer investigation including types of rock and extension of alluvial ground water bodies might yield better results. Common for all stations is a relatively small difference between frequent and rare low flows. This is shown by the ratio Q7L2/Q7L10 which is below 2.0 over the whole section.

In the Piedmont and Blue Ridge section the influence of topography is clearly visible in the very high and steady flows of the Blue Ridge. There

Figure 3

2 Year 7Day Low Flow

	x̄	s
I	.26	.16
II	.82	.19
III	.50	.092
IV	.19	.047
V	.29	.086
VI	.18	.045
VII	.060	.026
VIII	.46	.27
IX	.084	.049
X	.009	.01



5 Year 7 Day Low Flow

	$\bar{x}$	s
I	.22	.13
II	.63	.14
III	.37	.095
IV	.10	.095
V	.19	.073
VI	.10	.034
VII	.035	.022
VIII	.36	.25
IX	.039	.023
X	.005	.006

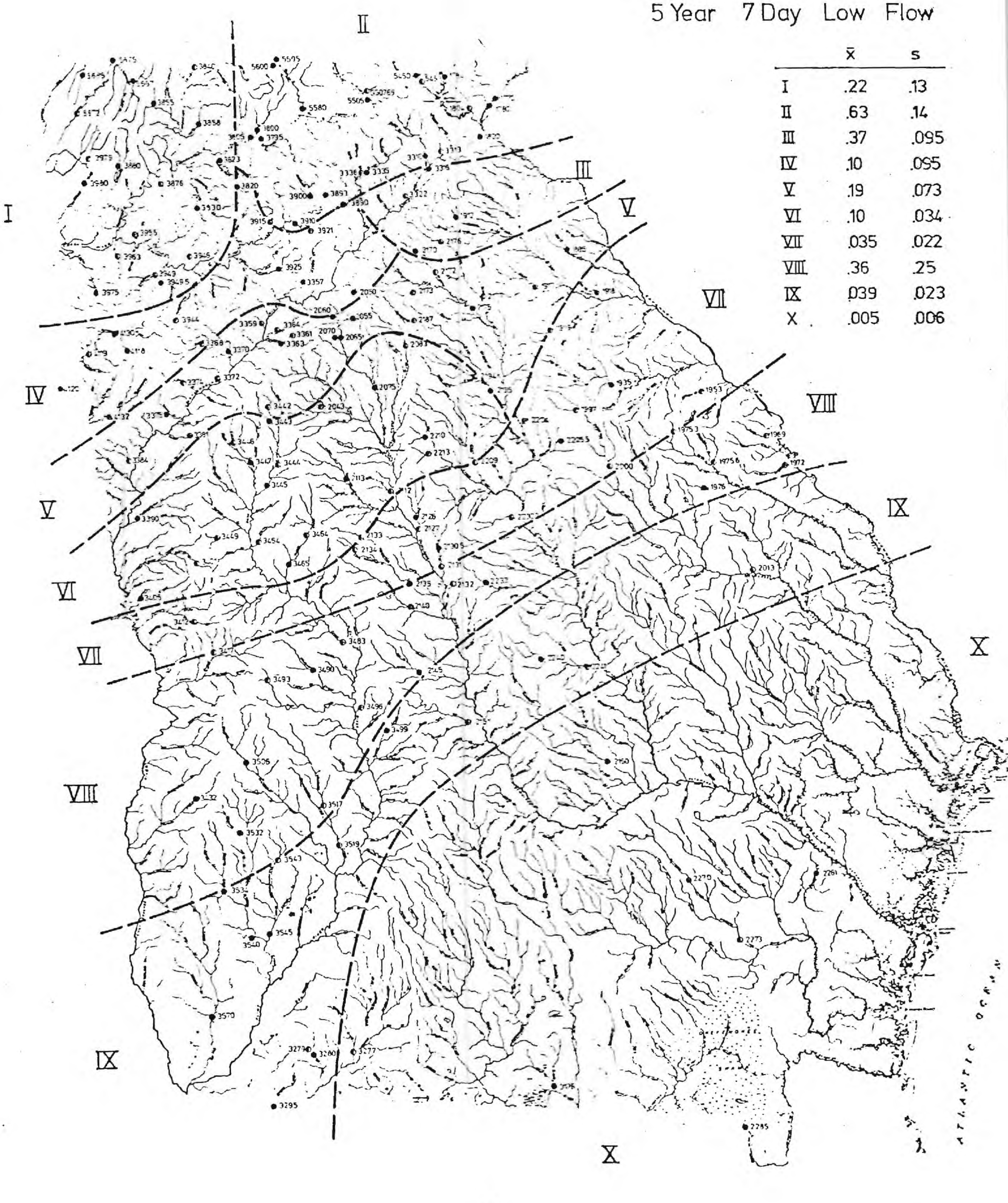


Figure 5

10 Year 7 Day Low Flow

	$\bar{x}$	s
I	.19	.12
II	.53	.13
III	.063	.028
IV	.14	.067
V	.068	.024
VI	.022	.018
VII	.33	.25
VIII	.029	.026
IX	.002	.004

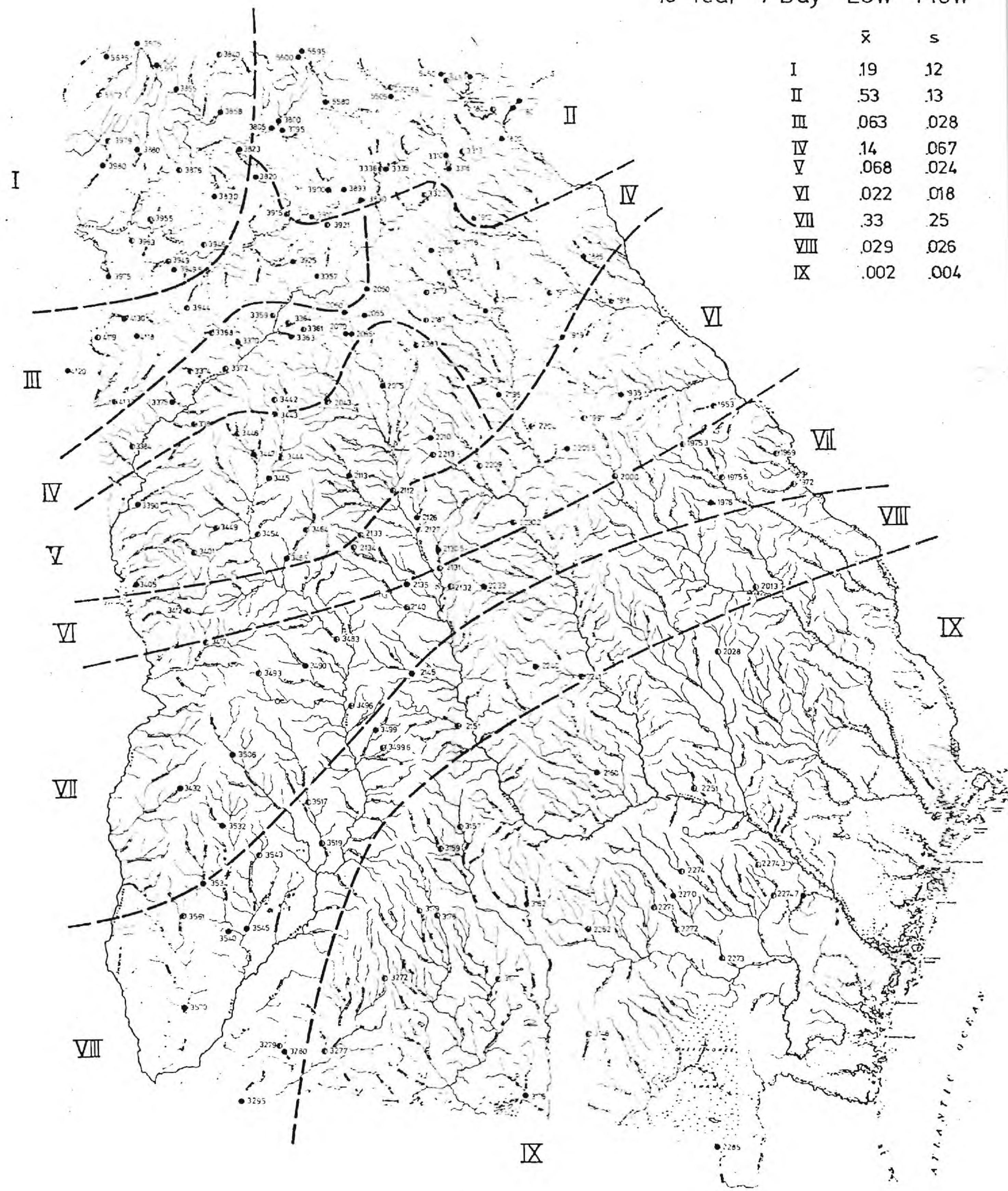
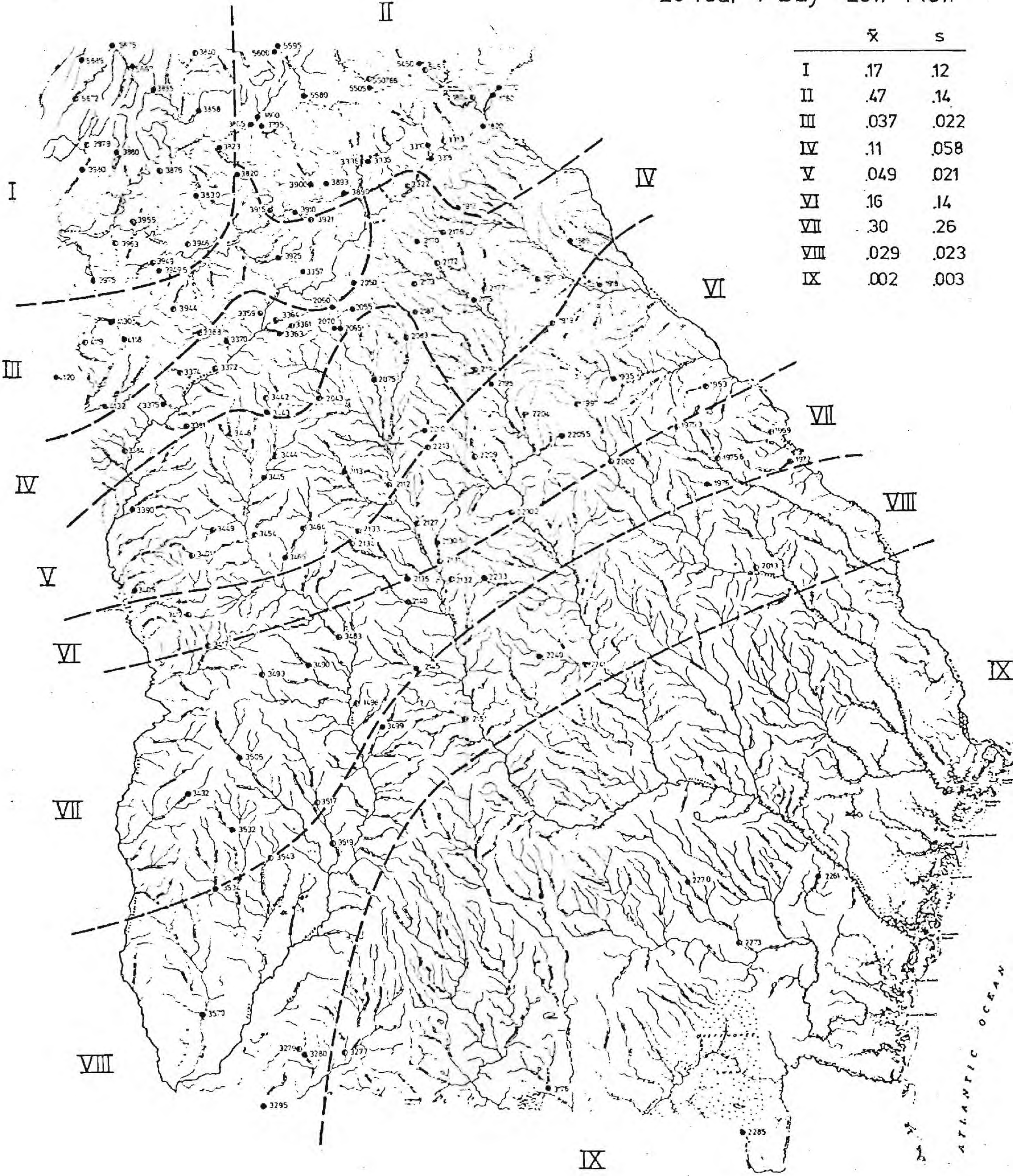


Figure 6

20 Year 7 Day Low Flow

	$\bar{x}$	s
I	.17	.12
II	.47	.14
III	.037	.022
IV	.11	.058
V	.049	.021
VI	.16	.14
VII	.30	.26
VIII	.029	.023
IX	.002	.003



Ratio Q7L2 / Q7L10

	$\bar{x}$	s
I	1.53	.32
II	3.08	1.51
III	1.66	.31
IV	3.51	1.09

Table 6. Low flow Characteristics of Outlined Zones

2 year return period

Zone	I	II	III	IV	V	VI	VII	VIII	IX	X
N	19	25	5	14	25	21	15	18	11	7
$\bar{x}$	.26	.82	.50	.19	.29	.18	.060	.46	.084	.009
s	.16	.19	.09	.05	.09	.04	.026	.027	.049	.010
$s/\bar{x}$	.62	.23	.18	.25	.30	.25	.44	.58	.58	1.13

5 year return period

Zone	I	II	III	IV	V	VI	VII	VIII	IX	X
N	19	25	4	14	26	19	16	18	18	7
$\bar{x}$	.22	.63	.37	.10	.19	.10	.035	.36	.040	.005
s	.13	.14	.095	.035	.07	.034	.022	.25	.023	.006
$s/\bar{x}$	.62	.23	.25	.33	.38	.35	.62	.70	.58	1.20

N = number of watersheds in zone

$\bar{x}$ = average of flows (cfs/mi^2)

s = standard deviation of flows (cfs/mi^2)

Table 7 Low Flow Characteristics of Outlined Zones

10 year return period

Zone	I	II	III	IV	V	VI	VII	VIII	IX
N	19	26	14	28	20	17	17	13	24
$\bar{x}$	.19	.53	.063	.14	.068	.022	.33	.029	.002
s	.12	.13	.028	.067	.024	.017	.25	.026	.004
$s/\bar{x}$	.65	.25	.45	.48	.36	.81	.75	.92	2.35

20 year return period

Zone	I	II	III	IV	V	VI	VII	VIII	IX
N	18	25	14	28	18	17	17	10	6
$\bar{x}$	.17	.47	.037	.10	.049	.016	.29	.029	.002
s	.12	.13	.022	.058	.021	.014	.26	.023	.003
$s/\bar{x}$	.69	.29	.60	.55	.44	.87	.89	.79	1.77

N = number of watersheds in zone

$\bar{x}$ = average of flows (cfs/mi^2)

s = standard deviation of flows (cfs/mi^2)

are distinct patterns of zones with different low flow yields in the Piedmont, but the most that can be said is that the zones generally lie parallel to the southwest-northeast direction of most geologic features.

In the eastern Piedmont the low flow yield gradually decreases towards the Fall Line. In the western part of the Piedmont a zone of higher flows follows the Chattahoochee River and cuts through the headwaters of the Yellow River. Above the Fall Line a band widening from west to east has very low flows. For an explanation, the several faults in this area might be named, but along the Chattahoochee there are areas with much greater tectonic disturbances which do not have particularly low flows. The ratio Q7L2/Q7L10 varies quite widely and without a visible pattern over the Piedmont area, but there are no extreme low values. Just above the Fall Line, there are a few stations at which 10-year low flows are as much as 10 times smaller than 2-year low flows, but at other stations the Q7L2/Q7L10 ratio is in an intermediate range.

Annual low flows in the Coastal Plain gradually decrease from very high values close to the Fall Line to almost zero in the lower Costal Plain. The zone of high flows is rather narrow in the east and widens towards the west. Even though it generally follows the older geologic formations (Cretaceous and Paleocene), flows stay high in areas with a not-too-thick cover of younger Eocene and Oligocene formations. The record station of the whole state in terms of flow rate at each return period and consistency of flow is Whitewater Creek which lies in this area. In the lower Coastal Plain the assumption that the yield is independent of the watershed size (or that it is at least a very minor factor) probably is not true and it might be possible to derive relations with watershed size as a parameter. However, this problem is not very important because low flows in small streams in this area are so close to zero even for small return periods that practical use in times of low flow is not possible.

In all the outlined zones the variance is quite high, and estimates based on the zone values, therefore, are subject to considerable errors. This is especially true for the higher return periods and areas with small low flow. In spite of that, they give a good tool for a first estimate of the low flow characteristics of an ungaged small stream. Furthermore, they indicate which gaged streams might be used for comparison and correlation. It is obvious that special characteristics of the watershed and man-made influences have to be taken into account separately.

Further research could concentrate on explaining the variance within these relatively coherent zones. It is possible that methods not successful in explaining low flow characteristics of large areas could give results used on smaller units.

CHAPTER III

REGRESSION BETWEEN PRECIPITATION AND LOW FLOWS

Introduction

This chapter deals with correlation between antecedent precipitation and the magnitude of low flow events at a gaged sites. If the parameters resulting from such a correlation could be regionalized, it would be possible to generate low flows at ungaged sites with known precipitation and to compute from them events with certain return periods by the usual statistical methods. In addition, conclusions about the influence of antecedent precipitation on low flow could be drawn.

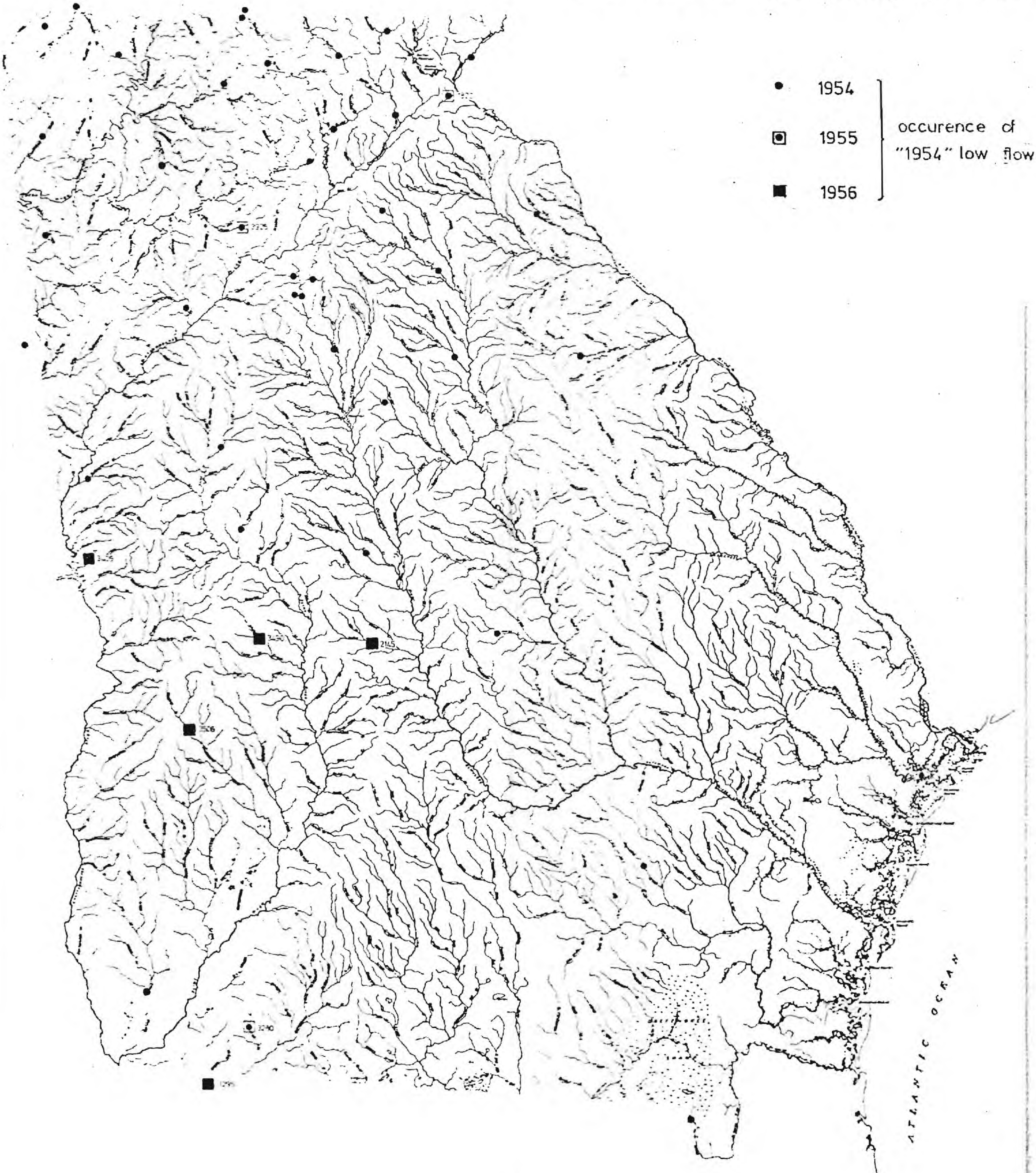
The first problem to be solved is the length of precipitation history involved. It has been mentioned in the literature [17] that large groundwater storages can influence low flows over several years, and there are indications for such a behavior in some small watersheds in Georgia. For the central and southern parts of the state, the drought of 1954 was the most severe in more than 30 years. In several streams, mostly in the upper Coastal Plain, the lowest 7-day low flow took place not in 1954, but in 1956, a year with precipitation slightly above normal (Figure 8). A similar lag effect occurred again after the less severe drought of 1968 when the minimal low flow at most of these gages occurred in 1969. If precipitation two years before the low flow event has an influence, annual precipitation values could be used in a regression equation of the type

$$Q7L_n = a + b\ (P)_n + c\ (P)_{n-1} + d\ (P)_{n-2}$$

n = current year

P = index for annual precipitation

Minimal Low Flow after Drought of 1954



Riggs [4] used as precipitation index the percentage of the long-term average. In this report P is defined as the precipitation minus the long-term average. In the variable P_n, the precipitation index of the cirrent year, events after the occurrence of the low flow are included (precipitation from October to December 1). The effect of this has not been investigated but it is not believed to be important.

Precipitation shortly before the occurrence of the annual low flow might have a different influence than precipitation in earlier periods of the year. Monthly precipitation has been chosen to investigate the impact of precipitation on low flow within the current year.

A regression between low flow and precipitation during periods earlier in the year would have the general form

$$Q7L_n = a + b(\text{Per } 1) + c(\text{Per } 2) + d(\text{Per } 3)$$

Per i = Precipitation index for a period i of one or several months within a year before the low flow events

Finally, a combination of the two previous models is possible:

$$Q7L_n = a + b(\text{per } 1) + c(\text{Per } 2) + d(P)_{n-1} + e(P)_{n-2}$$

For the following analysis, 6 watersheds in West Central Georgia were chosen (Table 8 and Figure 9). Four of them lie above and two lie below the Fall Line. Mountain Oak Creek, in spite of being completely in the Piedmont, behaves in many instances like streams in the Upper Costal Plain; it's low flows are quite high and showed a 2-year lag after the drought of 1954.

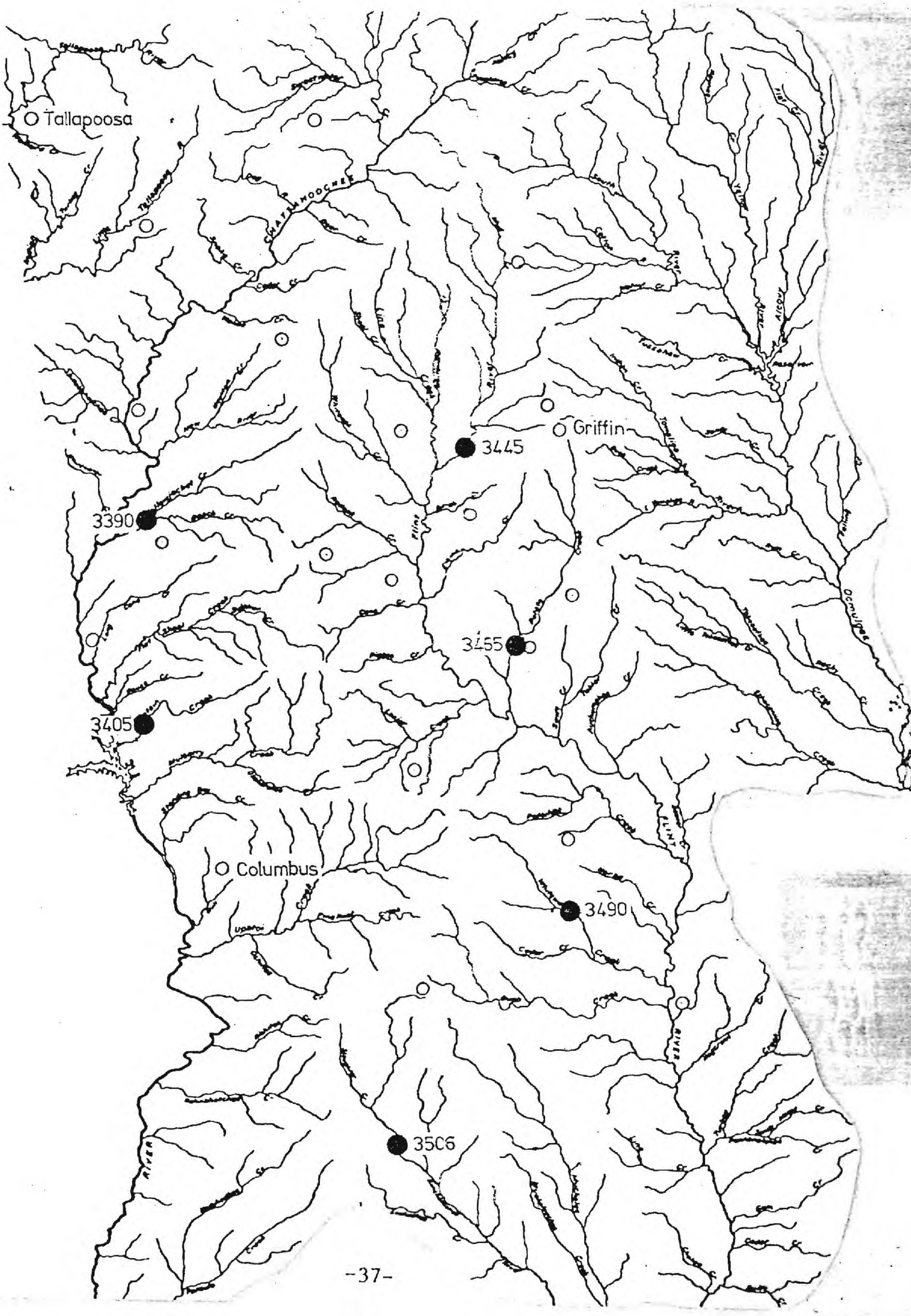
The longest common period of streamflow records for the 6 watersheds is 18 years, from 1952 through 1969, and this interval was used in this study. With the exception of the latest year, the values for the annual 7-day

Table 8. Watersheds used in Regression Analysis

Gage	Name of stream	Area mi^2	Q7L2 (cfs/mi^2)	Q7L10 (cfs/mi^2)	Q7L2/Q7L10
3390	Yellowjacket Creek	182.0	.192	.066	2.92
3445	Flint River	272.0	.180	.055	3.27
3465	Potato Creek	186.0	.145	.059	2.45
3405	Mountain Oak Creek	61.7	.259	.110	2.35
3506	Kinchafoonee Creek	197.0	.249	.127	1.96
3490	Whitewater Creek	93.4	1.328	1.135	1.17

Gages in West Central Georgia Used in Regression Analysis

Streamgage ● Raingage (state in 1960) o



low flows could be taken from the U.S.G.S. flow compilation [6].

The monthly and annual precipitation used in the regression study was an average over all the raingages in the West Central Georgia Climatic Region that were operating in the particular year. This eliminated the influence of scattered thunderstorm activity and made the results from the various watersheds more comparable.

All computation were made with the SPSS program package [18] using an arithmetical (Q7L = a + b x ...) as well as a logarithmic (ln(Q7L) = a + bx...) regression. Contrary to Riggs, it was found that in a graphical comparison the logarithmic regression model consistently performed better than the arithmetic, and only the results of the log model are shown in the following:

Procedures

Regression with Annual Values

Table 9 shows the result of a simple and multiple linear regression analysis with annual values. The results are not very satisfactory and indicate that the lag effect in the 3 watersheds 3490, 3506, and 3405 seems not to be too significant in normal years.

Regression with monthly values

To detect the period of the year with the greatest impact on the Fall low flows, a simple linear regression with a moving group of 3 months for October in the previous year to September in the current year was made (Figure 10). Two different behaviors can be seen: Low flows in watersheds above the Fall Line are fairly independent of precipitation in winter and early spring, but are influenced by late spring and late summer rainfall. The watersheds below the Fall Line react to precipitation during winter and summer, while precipitation during spring and early

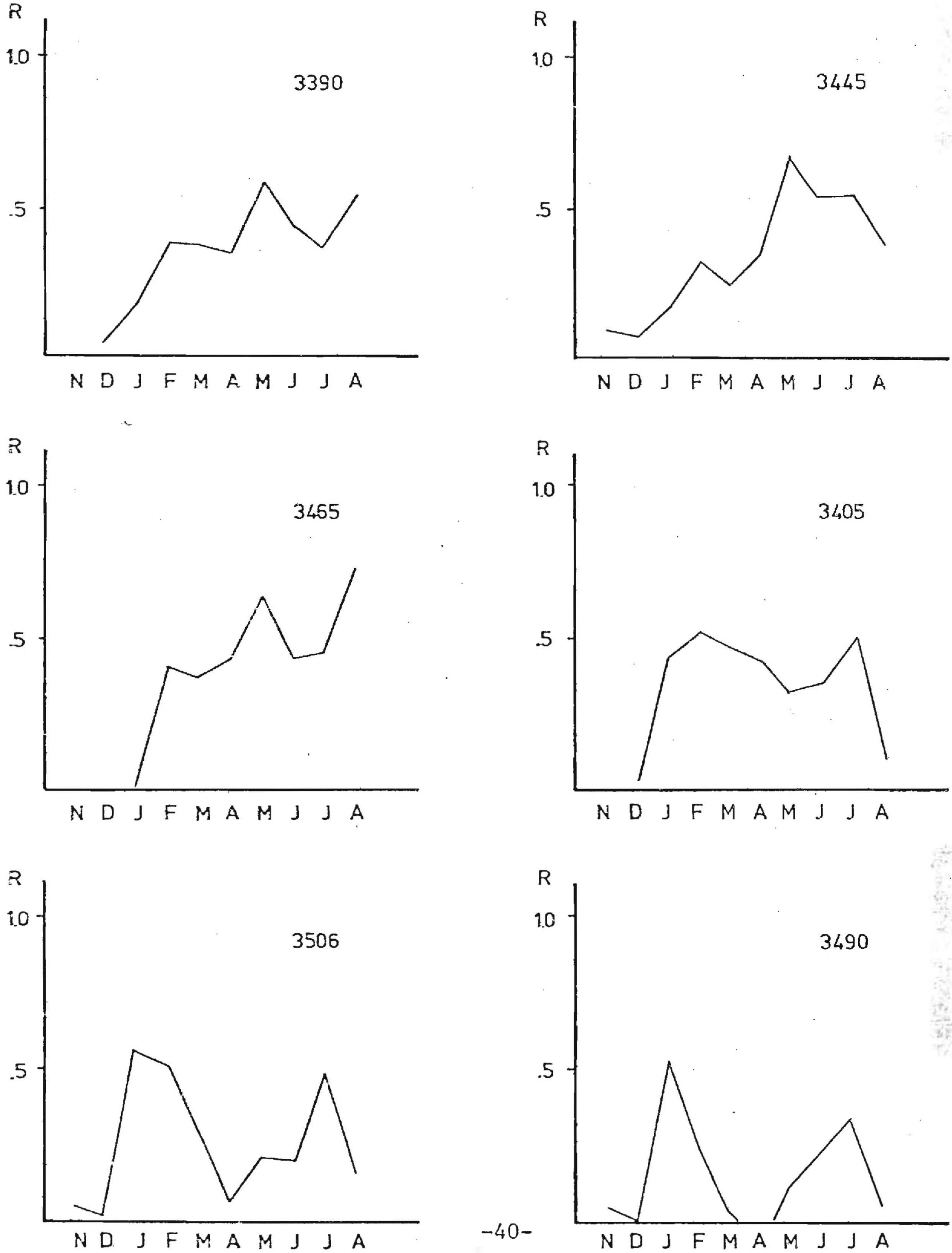
Table 9. Annual 7-day low flow with annual precipitation in previous years

Correlation coefficient R

$LN(Q7L)_n =$	$a + b(P)_n$	$a + b(P)_{n-1}$	$a + b(P)_{n-2}$	$a + b(P)_n + c(P)_{n-1}$	$a+b(P)_n+c(P)_{n-1}+d(P)_{n-2}$
3390	.50	.21	.26	.59	.64
3445	.52	.001	.44	.53	.67
3465	.67	.06	.10	.70	.70
3405	.38	.27	.30	.51	.61
3506	.18	.35	.25	.42	.52
3490	.09	.27	.22	.31	.41

Moving 3 Month Period

$LN(Q7L) = a + b(P)$ $\qquad$ $P = P_{m-1} + P_m + P_{m+1}$



fall seems to have almost no impact.

As mentioned earlier, Riggs used precipitation of two periods in a multiple regression:

$$LN(Q7L) = a + b\ (Per\ 1) + c\ (Per\ 2)$$

The first period covered the months from January to July; the second period consisted of August and September. The results of a regression with each of those periods separately and with the complete Riggs model are fair for the Piedmont gages, but unsatisfactory for the rest (Table 10).

Different trials were made to find better periods, the only restriction being a minimal length of 3 months for each of them. The best results are shown in Table 11. Gages above the Fall Line showed little change, compared to the Riggs model but the ones below the Fall line and 3405 were improved. Plots of computed vs. observed values for these regression equations are shown in Figure 11.

Combined Model

For all 6 watersheds, a multiple regression was made using the 2 optimal periods of the 2 period-model and the 2 previous years (Table 12). Correlation coefficients are only slightly higher than in the 2-period model, but the plots (Figure 12) show a clear improvement in the lower range.

To investigate how well values computed with the combined model could be used to determine statistical values, observed and computed values were plotted on log-Gumbel paper and straight lines were fitted (Figures 13 to 18). The estimated value for the 10-year recurrence interval is very satisfactory for each of the 6 watersheds, with errors around or below 20%.

Table 10. Annual 7-day low flows with Riggs model

correlation coefficients

$LN(Q7L) = a + b(Per\ 1) + c(Per\ 2)$

Per 1 = January to July

Per 2 = August and September

Gage	Per 1	Per 2	Riggs
3390	.59	.42	.66
3445	.55	.33	.59
3465	.64	.64	.81
3405	.65	.32	.68
3506	.49	.13	.49
3490	.27	.03	.28

Table 11. Optimal solutions for two-periods model

$$\mathrm{LN}\ (Q7L) = a + b(\mathrm{Per}\ 1) + c(\mathrm{Per}\ 2)$$

Gage	Per 1	R	Per 2	R	a	b	c	R_M
3390	Jan-Jul	.56	Jul-Sep	.52	-1.84	.049	.094	.67
3445	Jan-Jul	.55	Jul-Sep	.39	-2.05	.076	.085	.59
3465	Jan-Jul	.62	Jul-Sep	.79	-2.04	.070	.196	.82
3405	Dec-May	.54	Jun-Aug	.50	-1.67	.056	.107	.78
3506	Dec-Mar	.49	Jun-Aug	.48	-1.45	.067	.103	.75
3490	Dec-Feb	.52	Jun-Aug	.37	0.30	.021	.016	.62

R = simple correlation coefficient

R_M = multiple correlation coefficient

2 - Period Model

observed (o) vs. computed (c) low flows in cfs/mi²

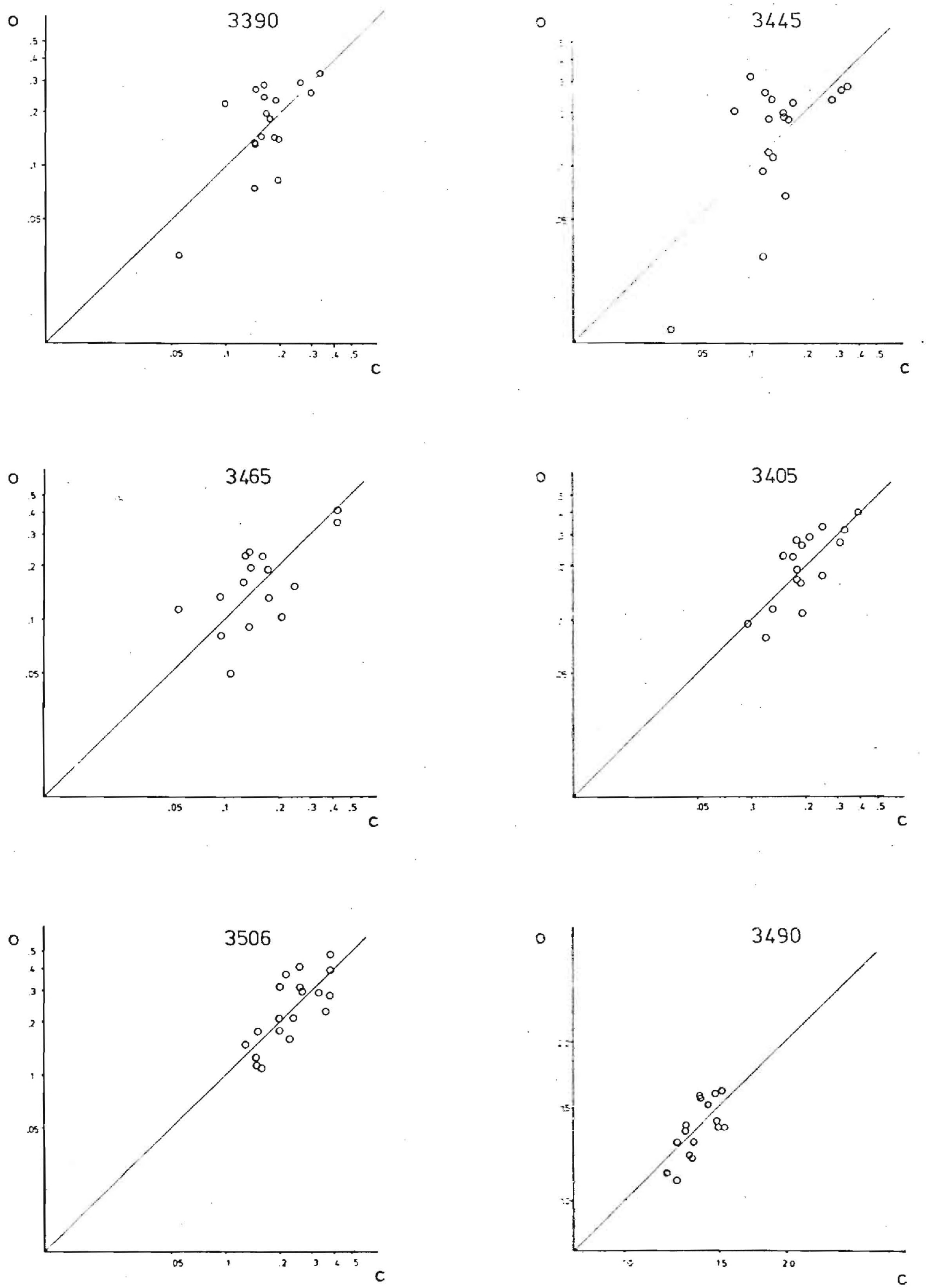


Table 12. Combined Model

$$LN\ (Q7L)_n = a + b(Per\ 1) + c(Per\ 2) + d(P)_{n-1} + e(P)_{n-2}$$

Gage	Q7L10	a	b	c	d	e	R
3390	.066	-1.94	.040	.136	.025	.054	.83
3445	.055	-2.17	.061	.151	.015	.059	.79
3465	.059	-2.12	.061	.233	.018	.031	.88
3405	.11	-1.72	.053	.092	.009	.010	.80
3506	.13	-1.48	.061	.091	.007	.008	.76
3490	1.14	0.29	.020	.014	.001	.002	.63

Figure 12

Combined Model

observed (o) vs. computed (c) low flows in cfs/mi²

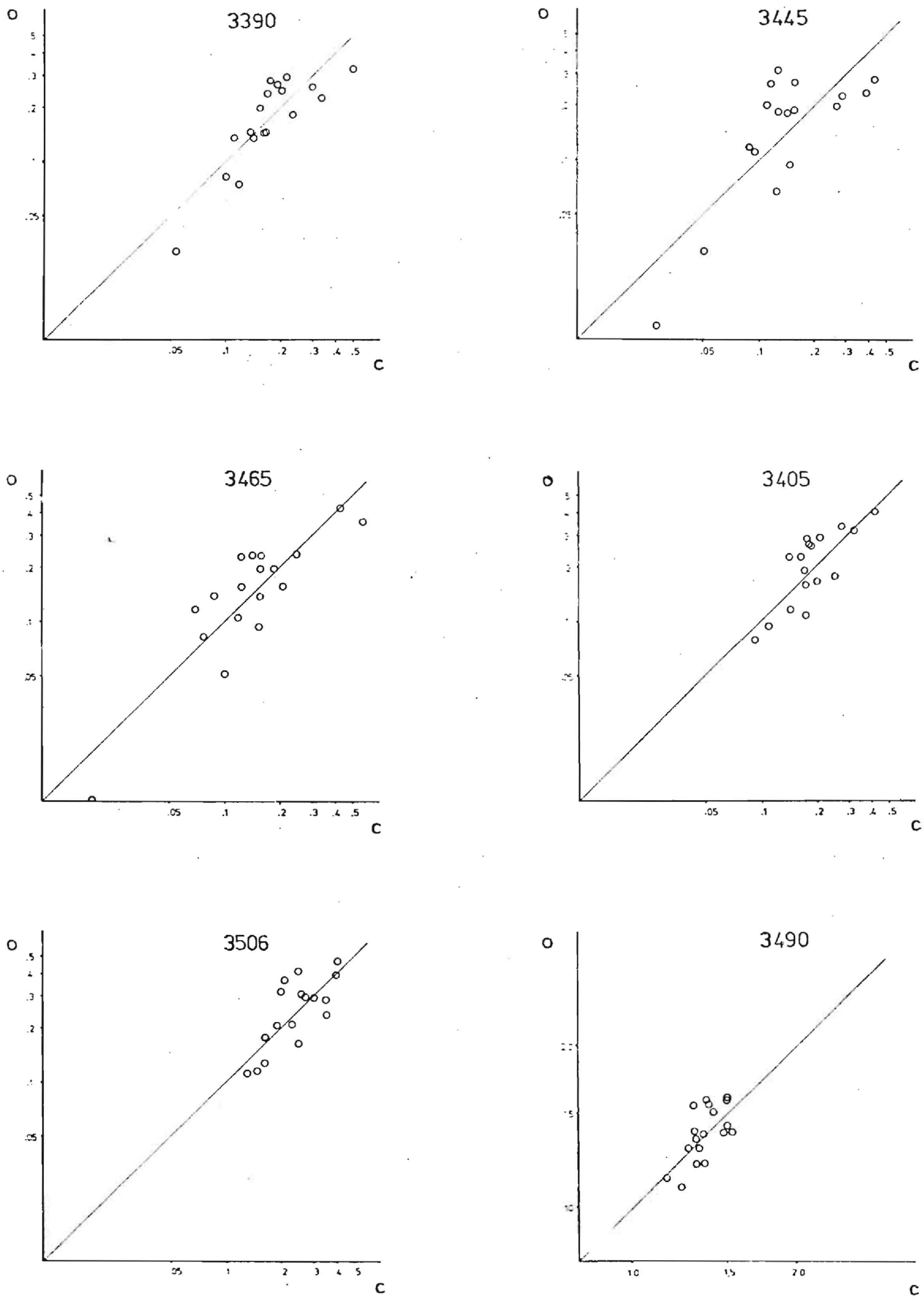


Figure 13 Statistical Distribution of Annual 7-Day Low Flows at Gage 3390

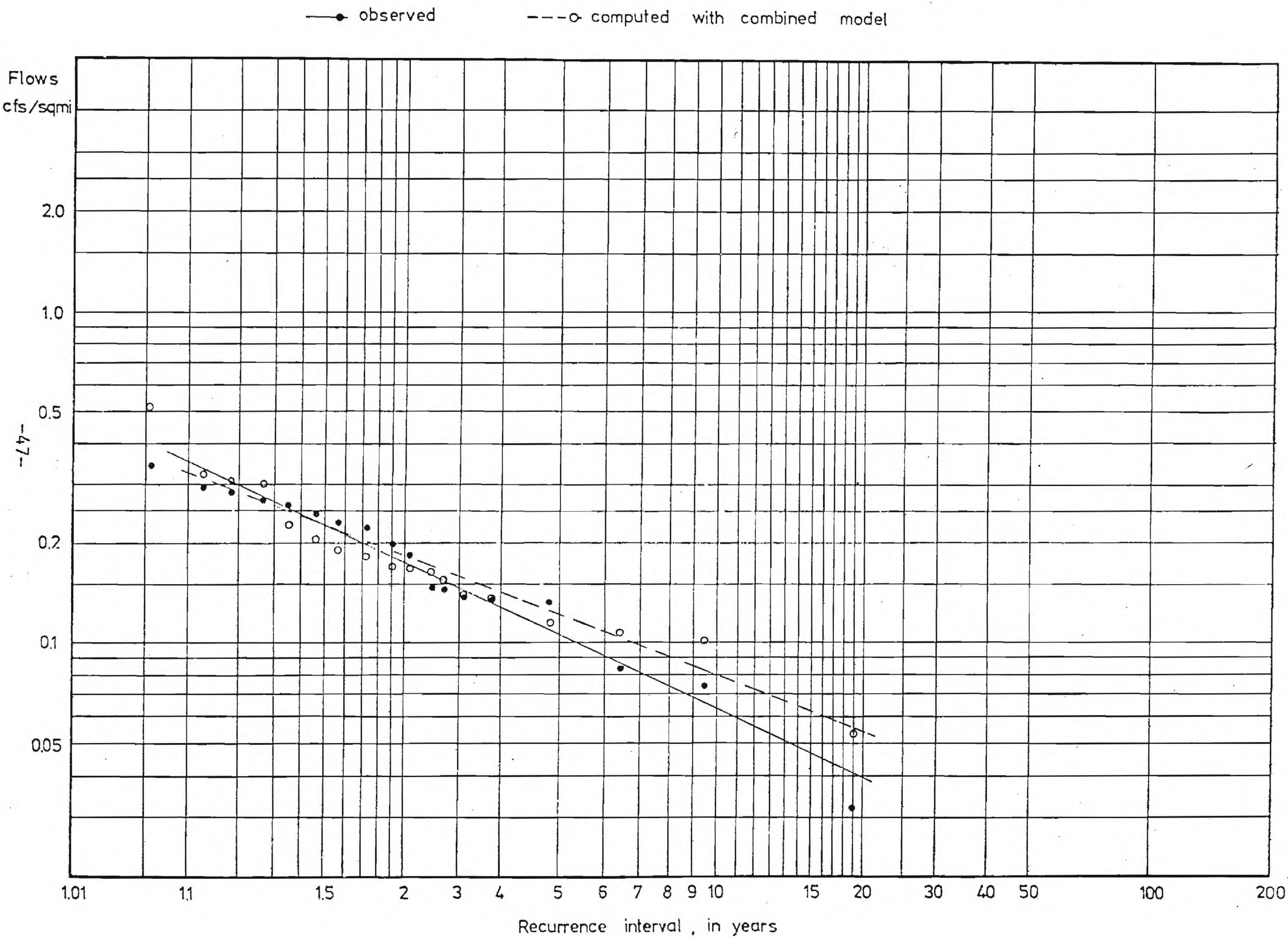


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Figure 14 Statistical Distribution of Annual 7-Day Low Flows at Gage 3445

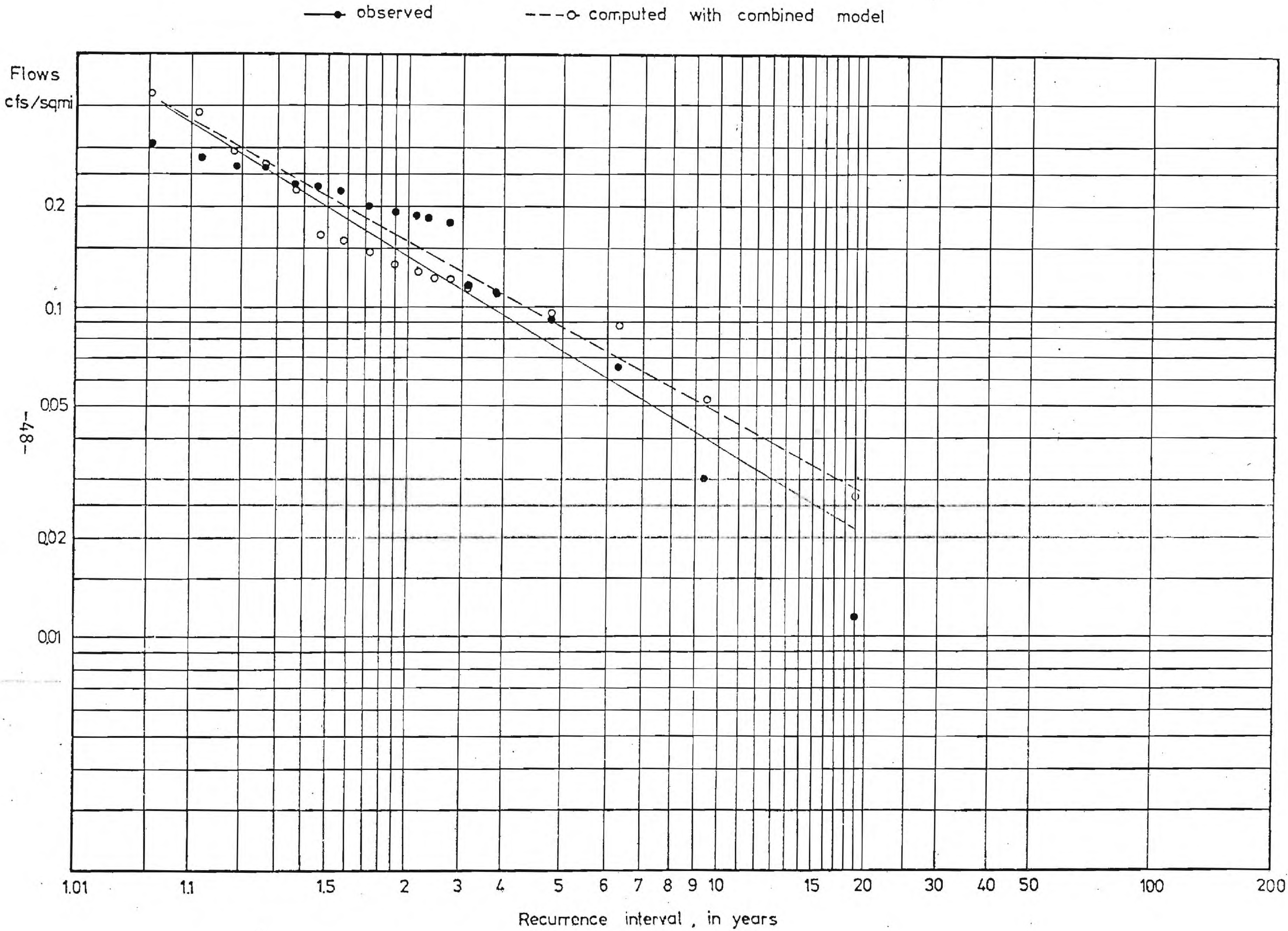


Figure 15 Statistical Distribution of Annual 7-Day Low Flows at Gage 3465

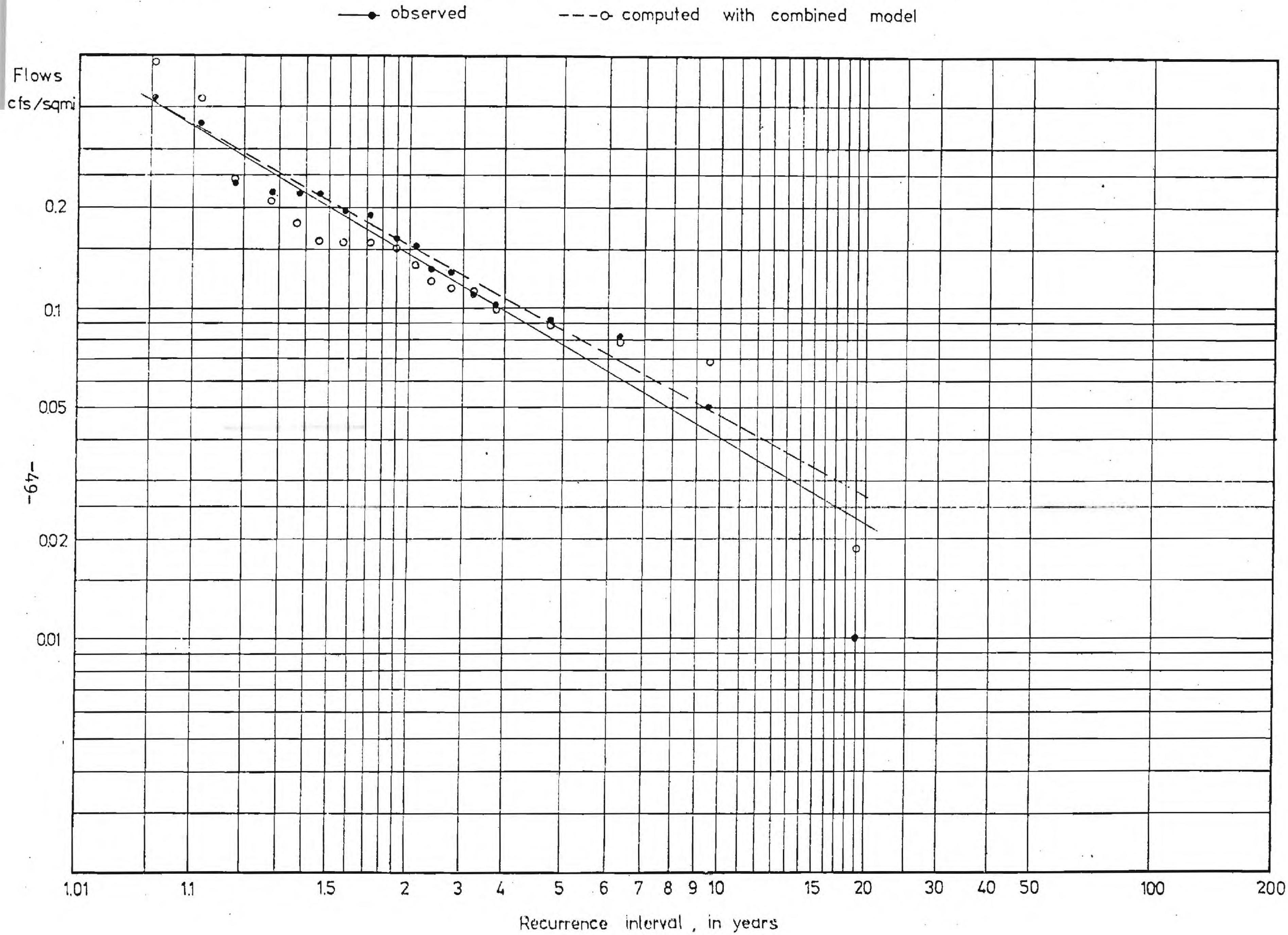


Figure 16 Statistical Distribution of Annual 7-Day Low Flows at Gage 3405

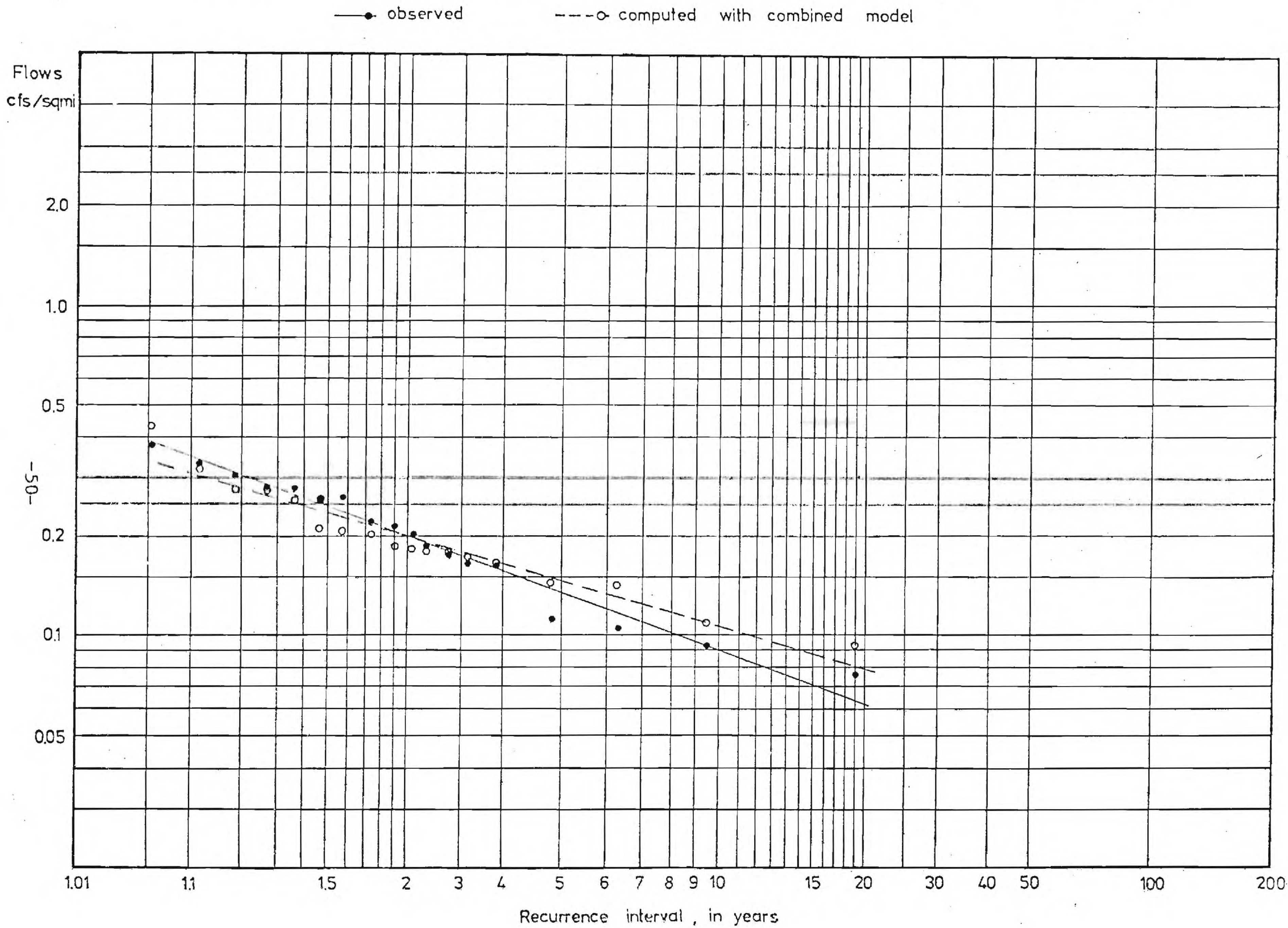


Figure 17 Statistical Distribution of Annual 7-Day Low Flows at Gage 3506

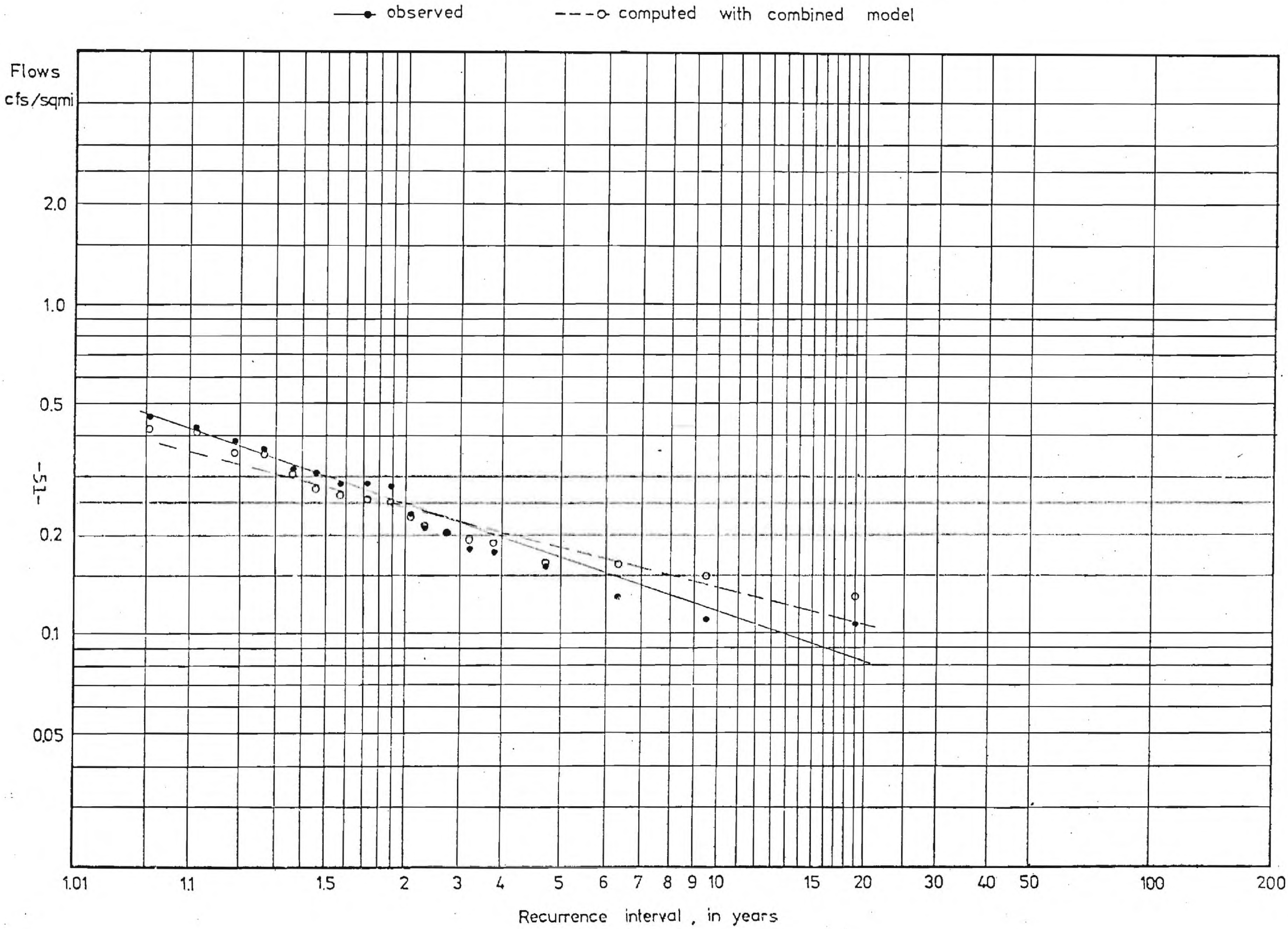
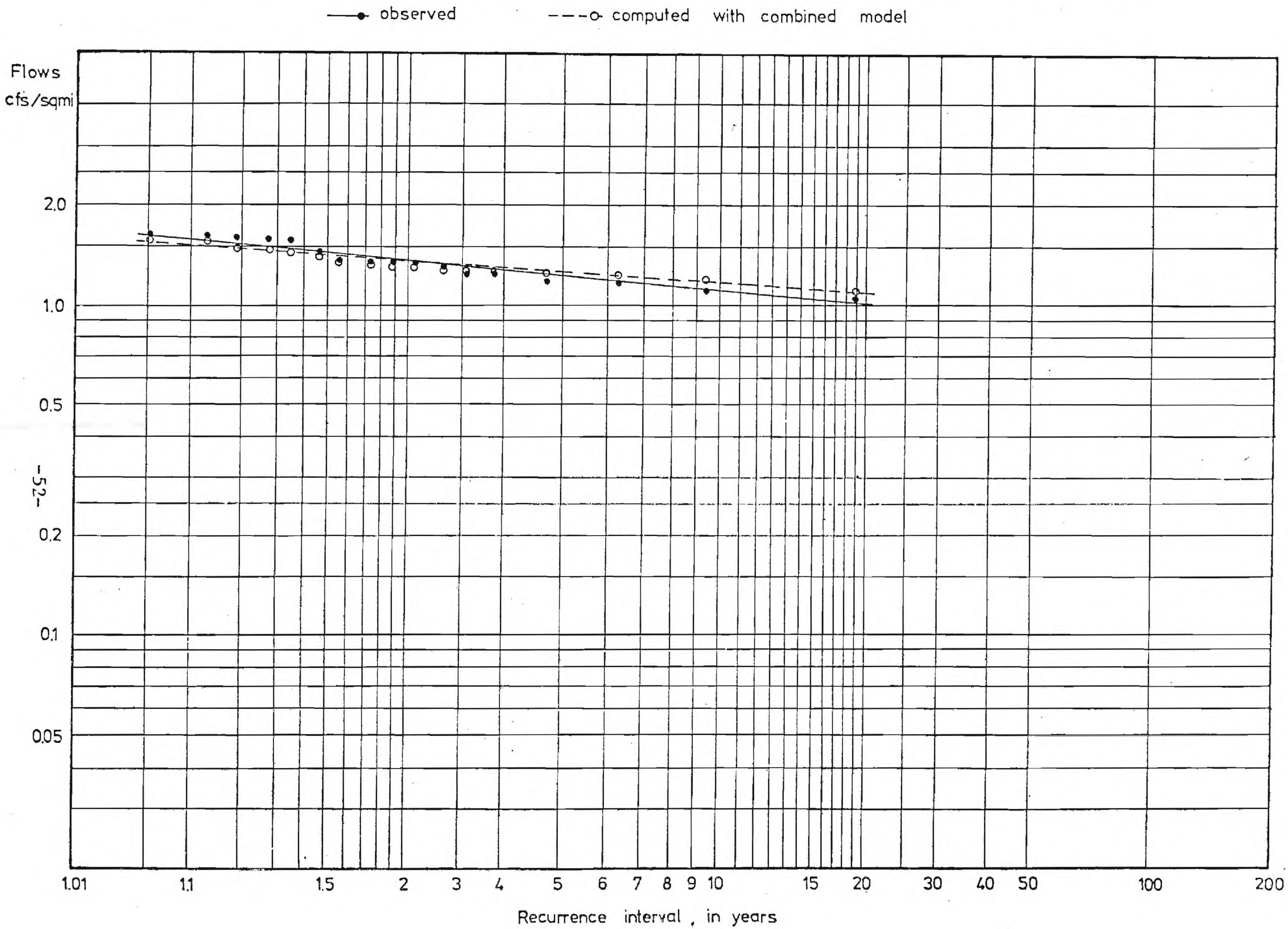


Figure 18 Statistical Distribution of Annual 7-Day Low Flows at Gage 3490



Other Attempts

One of the influences on low flow certainly is evaporation. Values of annual land-pan evaporation were included in a multiple regression, but they provided no improvement.

Correlations were made with different models between low flows at Gage 3465 and the precipitation at the Griffin raingage. Compared to the values obtained with an average precipitation over the West Central Division, the results were unsatisfactory, especially during the summer.

The influence of the time period during which the correlation is made was tested by splitting the previously used 18-years into two 9-year periods for the gages 3390 and 3490. The resulting correlation coefficients are shown in Table 13. During some of the short periods an excellent correlation between precipitation and low flow could be achieved. This is probably due to metereological trends with relatively little variance over a certain period. A good fit over a short time does probably not bring correlation coefficients that could be used generally. Much more data is needed for conclusions in this question.

Conclusions

The 18 years of record these conclusions are on which the analysis was based provides a relatively small data base; a few events could distort the different correlations considerably and a certain caution is therefore justified.

It is not possible to obtain a good correlation between low flows and annual precipitation values alone. Correlation between low flows and precipitation during periods within the current year gives much better results, especially if length and beginning of the periods are

Table 13. Influence of correlation period

correlation coefficients

$$LN(Q7L)_n = a + b(Per\ 1) + c(Per\ 2) + d(P)_{n-1} + e(P)_{n-2}$$

Gage	1952 - 1960	1961 - 1969	1952 - 1969
3390	.95	.69	.83
3490	.77	.69	.63

variables for each watershed. If the 2 previous years are used as additional variables, the results are certainly competitive with much more complicated deterministic models. Precipitation during periods 2 years in the past seems to improve the flow values in the lower range, which supports the theory of longtime influences on severe low flows.

There is a total of 9 parameters that can be investigated for regional patterns in the combined model:

- constant (a)
- influence of early period in the year (b)
- influence of late period in the year (c)
- influence of previous year (d)
- influence of year before (e)
- start of early period in the year
- start of late period in the year
- duration of early period in the year
- duration of late period in the year

For the watersheds below the Fall Line, which also have higher low flows, the constant a is larger. The influence of the early period b is fairly constant, with the exception of Whitewater Creek 3490, which is a exceptional case. The importance of precipitation in the later period in the year seems to be higher above the Fall Line, as is the one year lag coefficient d. The 2 year lag shows no distinct pattern.

For the beginning and duration of the optimal periods within the year, the situation is much clearer. Below the Fall Line, two short periods in winter and mid summer are optimal, above the Fall Line a long period from January to June and a short one from July to September are common for all streams except Mountain Oak Creek, which shows an intermediate behavior.

The conclusion that can be made from this investigation is that annual low flows are influenced strongly by precipitation in much earlier periods. Length and duration of these periods seem to be different in geologically dissimilar regions. Precipitation has an influence over several years only if it is strongly below normal. There are indications that the coefficients of the correlation equation could be regionalized, but further research is needed to clear this point. Another problem to be investigated is the effect of duration and position in time of the calibration period. Compared to a continuous simulation model, the period of record has to be much longer because there is just one event each year. This poses some difficulties because Georgia has relatively few small watersheds with long records.

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